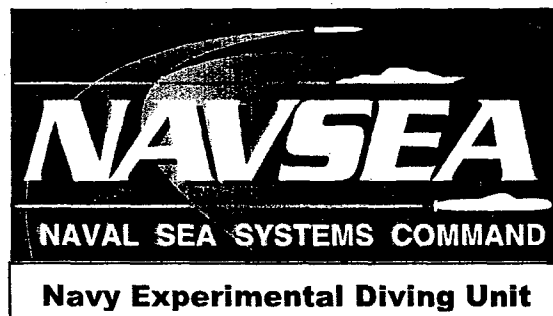


Navy Experimental Diving Unit (NEDU)  
321 Bullfinch Rd.  
Panama City, FL 32407-7015

NEDU TR 04-12  
April 04

## ON-SITE EVALUATION OF FIELD-BASED PROCEDURES FOR SCREENING DIVER'S AIR



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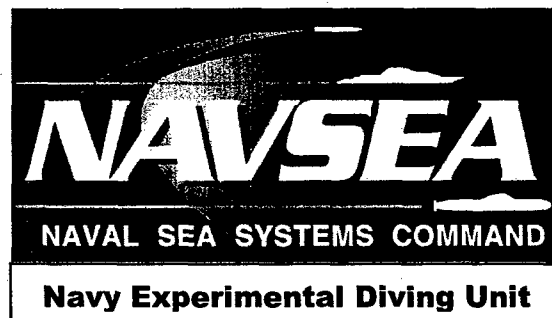
**Authors:** R.S. Lillo, Ph.D.  
J.M. Caldwell, B.S.  
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## INTRODUCTION

The U.S. Navy Diver's Air Sampling Program coordinates the mandatory semi-annual air purity testing of compressors used to supply diver's air in the Fleet.<sup>1</sup> Gas sampling kits supplied by a contract laboratory are sent to the field, where gas samples are taken and then returned to the laboratory for analysis. Analytical results are reported back to the field indicating pass or fail based on specifications for diving air in the *U.S. Navy Diving Manual*.<sup>1</sup> This approach is expensive, cumbersome, and potentially unreliable. Accuracy of results will depend partly on gas collection procedures in the field, which can be difficult to perform correctly, even under the best conditions. Relying on a contract laboratory also introduces concerns about the accuracy of the data and the long time delay between sampling and reporting of results.

For these reasons, we developed a set of procedures for screening diver's air on-site using three portable analyzers.<sup>2</sup> Our procedures are based on the current air purity specifications for diving air in the *U.S. Navy Diving Manual* and designed specifically to replace or supplement the present methods encompassing the U.S. Navy Diver's Air Sampling Program. We believe that such field-based testing of diving air compressors could:

1. eliminate current logistical requirements for ensuring sampling kit delivery,
2. eliminate potential sampling problems associated with collecting gas for later analysis,
3. provide credible data immediately to the person in the field, and
4. allow immediate re-testing to check questionable results and troubleshoot problems.

In addition, field testing may cost substantially less than the current program, particularly if the cost of the portable analyzers is spread across their expected lifetimes.

Although these procedures have received extensive testing in the laboratory, until now they have not been evaluated in the field under actual sampling conditions to afford bases for a decision about possible transition to the fleet. This report presents such an evaluation conducted at two on-shore test sites. Although this work does not directly address the current U.S. Navy interest in an on-line compressor monitor, these procedures are expected to be useful in evaluating and troubleshooting any future on-line monitors in the field.

## DESCRIPTION OF FIELD-BASED SCREENING PROCEDURES

This report provides an abbreviated description of our field-based screening procedures; additional details are included in the previously published report.<sup>2</sup>

Procedures were developed that allowed screening of compressor air on-site using three analyzers: (1) O<sub>2</sub>/CO<sub>2</sub>/CO analyzer, (2) total hydrocarbon analyzer, and (3) aerosol monitor; and a sampling apparatus. Air purity standards defined in the *U.S. Navy Diving Manual*<sup>1</sup> were used as the screening limits for diver's air:

O<sub>2</sub>: 20-22%,

CO<sub>2</sub>: 1,000 ppm (max),

CO: 20 ppm (max),

Total hydrocarbons (expressed in CH<sub>4</sub> equivalents, but excluding CH<sub>4</sub>): 25 ppm (max),

Oil, mist, particulates: 5 mg/m<sup>3</sup> (max), and

Odor: not objectionable,

where ppm = parts per million, and mg/m<sup>3</sup> = milligrams per cubic meter.

A brief description of each analyzer and sampling apparatus, a description taken from reference 2, follows below.

### AIR TESTING EQUIPMENT

#### O<sub>2</sub>/CO<sub>2</sub>/CO Analyzer

A portable analyzer (Anagas Dive Air, model DV 1.1; Geotechnical Instruments, Inc., Leamington Spa, England) was developed in collaboration with the manufacturer and allows simultaneous measurement of O<sub>2</sub>, CO<sub>2</sub>, and CO. This unit was adapted from the Geotechnical CO<sub>2</sub> analyzers that we have tested in the past for use on submarines.<sup>3-4</sup> Its small internal pump draws a gas sample into the unit where CO<sub>2</sub> is measured with a non-dispersive infrared detector. Oxygen and CO are measured with separate electrochemical detectors. Measurements are based on factory-generated calibration curves stored in the analyzer memory. On-site calibration involves zeroing of the O<sub>2</sub> and CO detectors with 100% N<sub>2</sub> followed by a one-point span of all three detectors with a calibration gas containing ~21% O<sub>2</sub>, ~1,000 ppm CO<sub>2</sub>, and ~20 ppm CO, balance N<sub>2</sub>. These steps adjust the position of the calibration curve to improve accuracy of measurements. Calibration concentrations were chosen to approximate the screening limits in order to minimize measurement errors about these limits. Based on laboratory

testing described in reference 2, accuracy of the analyzer at the limits is estimated to be:

O<sub>2</sub>: 21.0% ± 0.2%  
CO<sub>2</sub>: 1,000 ± 100 ppm  
CO: 20 ± 2 ppm

### Total Hydrocarbon Analyzer

A portable gas analyzer [Toxic Vapor Analyzer (TVA), model 1000B; Thermo Environmental Instruments, Inc., Franklin, MA], formerly manufactured by Foxboro Company, was adopted for use with diver's air. This is the same unit that has been incorporated in procedures NAVSEA adopted for screening diving air taken from the submarine air banks during operations involving the Dry Deck Shelter (DDS)<sup>5</sup> and the Advanced Seal Delivery System (ASDS).<sup>6</sup> For the DDS and ASDS, the TVA is configured with dual detectors, a flame ionization detector (FID) that detects volatile organic compounds (VOCs; i.e., those containing carbon, a group that includes all hydrocarbons), and a photoionization detector (PID) that provides additional diagnostic information. However, for the present procedures for typical air screening, the TVA is fitted with only an FID to provide the required "total hydrocarbon" reading, which actually is a total VOC measurement.

The FID uses the principle of hydrogen flame ionization for detecting and measuring VOCs to the ppm level. Electrically-charged species are formed when organic compounds are introduced into a small hydrogen-in-air flame and are detected by a collecting electrode. Common gases (e.g., CO<sub>2</sub>, CO) give no response. The air that is being sampled provides the O<sub>2</sub> for the flame combustion.

The U.S. Navy diving limit for total hydrocarbons of 25 ppm is in terms of methane. However, for these procedures, the TVA is calibrated with ~10 ppm isobutylene/balance air, rather than a methane standard. The isobutylene standard is nontoxic and produces an intermediate FID response compared to that of expected contaminants such as alkanes and aromatic hydrocarbons. Isobutylene is also currently used for Trace Gas Analyzer (TGA) calibration on submarines and for TVA calibration during DDS<sup>5</sup> and ASDS<sup>6</sup> air screening. Thus, using ~10 ppm isobutylene for diver's air testing, keeps the calibration gas requirement uniform for all these procedures and reduces the number of calibration gases needed in the field.

During calibration, the TVA is first zeroed using a charcoal filter adaptor to remove the isobutylene from the calibration gas, effectively delivering hydrocarbon-free air to the instrument. The filter is then removed, the normal TVA probe installed, and the calibration gas is sampled for span adjustment. The TVA is then used to screen diver's air with and without the charcoal filter. Because the charcoal removes trace organic vapors heavier than methane, ethane, and some related compounds, filtering allows the methane concentration to be determined. The methane value is then subtracted from

the unfiltered reading to calculate a total hydrocarbon concentration, which excludes methane.

Because the FID responds to different compounds with differing sensitivities, it is necessary to adjust the analyzer reading in isobutylene equivalents to the desired methane equivalents. To do this, the TVA reading is multiplied by 1.5, which is the manufacturer's reported value for isobutylene/methane sensitivity, and which has also been confirmed by our laboratory. However, since different types of analyzers will respond differently to specific contaminants, total hydrocarbon measurements of diver's air will depend not only on the nature of the contaminants but also on the specific analyzer used. For these reasons, estimating the accuracy of the TVA in measuring total hydrocarbons would not be particularly meaningful. Thus, the emphasis during the laboratory evaluation was on defining the TVA's measurement linearity for a number of VOCs ranging from 0 up to ~20 ppm<sup>2</sup>. This error was found to be less than 0.5 ppm.

### Aerosol Monitor

A portable off-the-shelf aerosol monitor (Personal/DataRAM, model pDR-1000; MIE, Inc., Bedford, MA) is used to measure the aerosol concentration (oil, mist, and particulates) of diver's air. This analyzer is a photometer that uses the principle of light scattering to measure the concentration of an aerosol. The response of the monitor has been calibrated at the factory with a fine test dust. However, the angle and intensity of the scattered light depend on the refractive index and size of the particle. Therefore, it is important that the monitor reading be corrected for the oil used in the compressor being tested.

The Personal/DataRAM was evaluated in the laboratory to determine calibration factors for different oils commonly used in air compressors.<sup>2</sup> The calibration factors ranged from 0.4 to 0.6 for six oils including several synthetic lubricants. Based on these results, a calibration factor of 0.5 was incorporated into the operating procedures of the Personal/DataRAM for screening diver's air. Experience will dictate whether this correction factor should be adjusted for oils that have not yet been tested.

The Personal/DataRAM is generally designed for indoor use at locations away from strong breezes or winds. Air passively (i.e., undirected by a pump) moves by convection, diffusion, and adventitious motion into the optical sensing chamber of the device via the slots under the top cover of the monitor. For sampling outdoors and under high flow conditions (e.g., ducts and stacks), active sampling instruments configured with special inlets designed to promote representative sampling are required. For compressor air screening, we replaced the top cover of the Personal/DataRAM with a custom-made plastic "flow-adaptor," fabricated in-house.<sup>2</sup> In this configuration, the flow-adaptor allows a very low flow of the compressor air to be directed through the sensing chamber of the DataRAM; a small vane flowmeter monitors the flow. Overall accuracy of Personal/DataRAM measurements of compressor air is conservatively estimated at  $\pm 40\%$  relative.<sup>2</sup>

## Sampling Apparatus

A sampling apparatus, defined here as the "air-sampler" was designed to sample output from the high-pressure compressor with the preceding three instruments. The primary concern with any sampling device is its potential effect on the constituents of the gas that will be measured. Here, the primary concerns would be with (1) loss and/or gain of VOCs as the air flows through the air-sampler and (2) loss of aerosols through dropout of particles as they impacted the inside surfaces of the hardware. The fixed gases ( $O_2$ ,  $CO_2$ , and  $CO$ ) are much less likely to be affected by the sampling process.

The air-sampler, with its all metal, stainless steel construction, including three ball valves and a 5,000-psi pressure gauge, should be acceptable for most VOC sampling if the apparatus is kept clean and free of oil, grease, and solvents. With its wide bore tubing, large valves, and straight-through flow path, the device was designed to avoid problems with aerosol loss and any resulting underestimation of the actual aerosol concentration. Test results confirmed the air-sampler's reliability for oil mist sampling.<sup>2</sup>

## **INTERPRETING FIELD-BASED SCREENING RESULTS**

1. High  $CO_2$ ,  $CO$ , or TVA (hydrocarbon) readings  
or  
Low  $O_2$  reading  
or  
Objectionable odor
  - a. Compressor intake air may be contaminated due to engine exhaust or shipboard activities such as painting, cleaning, and equipment repair.
  - b. Compressor intake air may be contaminated due to failure to ventilate closed spaces (e.g., submarine) where air intake is located, prior to compressor operation.
  - c. Compressor malfunction or failure,
  - d. Filters on compressor need servicing.
2. High DataRAM (oil, mist, particulates)
  - a. Compressor malfunction or failure,
  - b. Filters on compressor need servicing.

## **ACCURACY OF FIELD-BASED SCREENING PROCEDURES**

The acceptable level of measurement accuracy for screening diver's air depends on the air purity standards and the health and operational consequences from making either of

two errors: (1) false positive responses (i.e., falsely concluding that the air fails to meet the standards) or (2) false negative responses (i.e., falsely concluding that the air meets the standards). False positive outcomes are more an operational, than a health concern, in terms of readiness and the ability to perform a mission in a timely manner. False negative readings are a diver health issue that depends on the rationale for the standards and the implications of exceeding them. Unfortunately, the justification is unclear for many current limits for gas contaminants contained in various U.S. Navy documents, including those in the *U.S. Diving Manual*<sup>1</sup>. For hyperbaric exposures, lack of information about contaminant effects on humans or animals at pressure is an additional problem.

The Diver's Air Sampling Program has not revealed any apparent problems with adverse acute symptoms from using air from compressors that had passed the sampling standards. However, because actual sampling is routinely done only semiannually, past "success" of the program may have little meaning. Review of some NAVSEA data consisting of ~2800 samples from January 1999 to August 2001 revealed an ~6% failure rate for meeting the *Diving Manual* criteria. The most common failures were CO (2.5%) and CO<sub>2</sub> (2.1%); both total hydrocarbons and oil mist failures were each less than 1%, and odor was detected in less than 0.5% of total samples. Only 1 case of failing the O<sub>2</sub> limit occurred, and only 0.4% of the failures were multiple failures in which two or more of the criteria were exceeded in the same sample. Thus, because high CO<sub>2</sub> and CO seem to be the two main reasons for air to fail, there may be minimal experience with use of diving air that approaches or exceeds the limits for the other contaminants.

The apparent lack of significant diving problems should not be read as an endorsement of either the safety or suitability of the limits to avoid at least acute symptoms during diving. Certainly, the limit for total hydrocarbons remains an issue because of the high toxicity attributed to relatively low levels of some species, such as aldehydes and ketones, that have been observed following compressor malfunction or failure<sup>7-8</sup>. In addition, we have been recently using gas chromatography/mass spectrometry to examine selected air samples from the Diver's Air Sampling Program, samples that the Program's contract laboratory reported to have greater than 10 ppm total hydrocarbons with FID. Our examination has provided data on specific VOCs in the samples and confirms our longstanding opinion about the limited usefulness of a total hydrocarbon measurement, particularly when gas chromatography (GC) with an FID and methane as the calibration standard is used. Here, we have commonly found that the FID, with its strong carbon number-dependent sensitivity, greatly overestimates the actual concentration.

The O<sub>2</sub>/CO<sub>2</sub>/CO monitor, with its high accuracy, is not expected to increase the measurement error of the three constituents it examines. The TVA analysis, like the current hydrocarbon screening method using gas chromatography in the laboratory, depends on the response factors of the instrument for specific species and the nature of the organic contaminants. However, we should not presume that the TVA reading is less reliable than the laboratory value. In fact, TVA analysis of hydrocarbons in the field

might produce a more accurate index of hydrocarbon contamination, as no gas collection and storage, which could potentially compromise the sample, are involved. Furthermore, NEDU testing and response factor data from the manufacturer have shown that the FID response with the TVA depends much less on carbon number than the standard FID used for GC does<sup>9</sup>. For this reason, the TVA reading in methane equivalents, while still an overestimation, should more closely approximate the total concentration of any VOC mixture.

The  $\pm 40\%$  error estimated for DataRAM measurement of aerosols is probably at least as accurate as the current system, which requires direct collection of aerosols on filter paper in the field, subsequent weighing of the filter in the laboratory, and calculation based on estimated gas sample flow rate and time.

Although the pass/fail decision depends on whether the air purity standards are met, close attention should be paid to any measurements that are abnormal but may still meet the limit. These suspect readings may alert the user to conditions such as a failing compressor or contaminated intake air that may soon deteriorate resulting in unacceptable diver's air. Thus, caution should be used to avoid merely declaring that a compressor unconditionally passes or fails. Certainly, the ability to easily re-test the air with these field-based procedures allows the follow-up that these types of situations may require.

## **ONE-YEAR FIELD TEST**

All procedures (including data sheets) for the field test were defined in a written test plan, which needed to be modified a number of times during the course of this project. The last revision of the data sheet is contained in **Appendix A**. A brief description of the field test is presented below.

### **SUMMARY**

The field test consisted of screening the output air from two compressors, using the NEDU field-based procedures, at each of two on-shore sites at pre-scheduled times during a one-year evaluation. The two sites were 1) the Mobile Diving and Salvage Unit Two (MDSU-2), Norfolk, VA and 2) the Navy Diving and Salvage Training Center (NDSTC), Panama City, FL.

The purpose of the field test was to evaluate the screening procedures at operational sites in terms of (1) variability of measurements, both short-term ( $< 10$  min; i.e., "precision") and within the day, (2) accuracy of the measurements, (3) reliability of test equipment, (4) the need for any changes to the procedures, and (5) ability to train on-site personnel.

## EQUIPMENT

The equipment requirement for each test site was as follows:

### 1. Analyzers

- a. Two O<sub>2</sub>/CO<sub>2</sub>/CO Analyzers (Anagas Dive Air, model DV 1.1; Geotechnical Instruments, Inc., Leamington Spa, England)
- b. Two Toxic Vapor Analyzers (TVAs, model 1000B; Thermo Environmental Instruments, Inc., Franklin, MA), each with:
  - 1) Charcoal adaptor and charcoal
  - 2) Two TVA H<sub>2</sub> cylinders
  - 3) AC power cord for recharging internal batteries
  - 4) H<sub>2</sub> fill whip
- c. Two Personal/DataRAM aerosol monitors (Personal/DataRAM, model pDR-1000; MIE, Inc., Bedford, MA) and extra batteries

### 2. Miscellaneous equipment

- a. One "air-sampler" used to screen compressor air using the three analyzers
- b. One high-purity regulator configured to connect to the compressor to take air samples using high-pressure gas collection cylinders
- c. One high-purity regulator for calibration gas cylinder
- d. One high-purity regulator for zero N<sub>2</sub> cylinder
- e. Three sets of branched sampling tubing (Tygon, ~1 foot long, with Y-connector), for analyzer calibration and compressor sampling
- f. Syringe barrels and 3-way plastic stopcocks, for analyzer calibration and compressor sampling
- g. Two calibration gas cylinders (one, a spare) containing 4 components in balance N<sub>2</sub>: nominally 21% O<sub>2</sub>, 1,000 ppm CO<sub>2</sub>, 20 ppm CO, and 10 ppm isobutylene
- h. One gas cylinder of zero N<sub>2</sub> (CO<sub>2</sub>-free, hydrocarbon free) for zeroing the O<sub>2</sub>/CO<sub>2</sub>/CO analyzers
- i. One gas cylinder of high-purity H<sub>2</sub> for filling the individual TVA H<sub>2</sub> cylinders



- j. 12 high-pressure gas collection cylinders (with data tags), previously evacuated, for compressor samples
- k. One digital thermometer, for measuring ambient air temperatures at compressor sites, extra batteries
- l. One flowmeter (rotameter) for monitoring gas flow during analyzer calibration and compressor sampling
- m. One set of manufacturer's manuals for the 3 analyzers

All equipment, except for the gases, was purchased, assembled, and tested at NEDU prior to delivery to the test sites to insure correct operation. Calibration, N<sub>2</sub>, and H<sub>2</sub> gases were ordered by NEDU and delivered to the test sites prior to the first training visit. Gas cylinders were returned to the vendor when empty or at the end of the testing; additional gases were supplied by NEDU as needed. Following the 1-year test, all equipment was returned to NEDU.

### **PRELIMINARY TRAINING**

All equipment (except gases) and copies of the test plan (including procedures and data sheets) were distributed during an on-site training visit by NEDU personnel to the two test sites prior to the start of the testing. Training consisted of:

- 1. Instruction on the field-based procedures,
- 2. Review of the test plan detailing exactly how the test was to be performed and data was to be recorded,
- 3. Use of the 3 analyzers, and
- 4. Instruction on collection of air samples using evacuated high-pressure cylinders.

### **TESTING**

- 1. All testing equipment was stored inside at the test locations when testing was not being done.
- 2. Each compressor was tested one day ("test day") every two weeks during the one-year evaluation. For convenience, the same two compressors at each site were used for the entire evaluation unless this became unfeasible for any reason. On each test day, both compressors were sequentially screened four different times at two-hour intervals. Prior to each of the four screenings of the two compressors, analyzers were re-calibrated. The first screening consisted of a series of five replicated measurements taken over a time period of less than 10 min to evaluate

short-term variability of the procedures. The other 3 screenings consisted of a single set of air measurements.

3. Two complete sets of analyzers (labeled "A" and "B") were evaluated at each site although only one set was used on each test day. Analyzer sets were alternated every 2 test days; this schedule facilitated collection of air samples (item 4). When any analyzer(s) failed during testing, a working analyzer was substituted from the other set.
4. On alternate test days (every four weeks), one set of air samples was collected from each compressor immediately following one of the screenings, using evacuated high-pressure gas cylinders. By alternating analyzer sets A and B every two test days (item 3), air samples were taken using first in conjunction with set A and then with set B. These samples were taken with assistance from NEDU personnel during the monthly site visits (see below). Air samples were also to be taken anytime unusual readings with the portable analyzers were observed or an objectionable odor detected, as these are situations when the ability to detect problems would be important. These air samples were subsequently analyzed by the NEDU Gas Analysis Laboratory to compare to the measurements made in the field. Cylinders were then re-evacuated by NEDU and sent back to the test sites for additional sampling.
5. All screening results and air collection information were recorded on the NEDU data sheet. During testing, ambient temperatures (and weather conditions) were also recorded. Completed data sheets were collected by NEDU personnel during the monthly site visits.
6. Air samples taken in item 4 were analyzed in the laboratory using GC with 1) a thermal conductivity detector for O<sub>2</sub> and 2) a methanizer/FID for CO<sub>2</sub> and CO. Samples were also analyzed for individual VOCs using GC to compare to the TVA hydrocarbon measurements. This approach for hydrocarbons was thought more useful than performing yet another total hydrocarbon analysis (here using GC), which like all such measurements, would vary with the specific procedure. The VOC analysis used GC configured with FIDs with 2 different columns supplied by Supelco (Bellefonte, PA): 1) a 10-ft long, 1/8-inch stainless steel packed column, 3% SP-1500 on 80/120 Carbopack B, and 2) a 60-m long, 0.53-mm id, wide bore glass capillary column, Supelcowax 10, 1.0 micron film. These columns allowed detection of a wide range of VOCs below the 0.1 ppm level. Primary gravimetric standards with concentrations close to observed values were used to quantify all GC results.
7. The ability of experienced Navy personnel to teach the air screening procedures to inexperienced persons was evaluated. The goal was to have one experienced tester and one new person work together for at least three consecutive test days: (a) on the first test day, the experienced tester demonstrates the procedures to the trainee, (b) on the second test day, the trainee performs the procedures while the tester

talks him through the procedures, (c) on the third test day, the trainee performs the procedures with the tester nearby and receives assistance only when needed.

8. The current U.S. Navy Diver's Air Sampling Program, and its contract laboratory, remained the standard for pass/fail of diver's air for compressors at both test sites during this testing period.
9. If any problems including analyzer malfunction occurred during the field testing, NEDU was to be contacted immediately through the information on the cover page of the test plan.

## **MONTHLY SITE VISITS**

NEDU personnel conducted site visits every 4 weeks to:

1. Collect air samples in cylinders,
2. Pick up data sheets and deliver re-evacuated cylinders,
3. Discuss testing progress and problems, and
4. Determine the need to adjust the test plan or procedures.

## **RESULTS AND DISCUSSION**

### **STARTUP PROBLEMS**

A few problems occurred with some of the test equipment during the initial part of the field test. These included (1) an apparent short in the electrical system of one of the O<sub>2</sub>/CO<sub>2</sub>/CO analyzers that caused the battery to drain quickly when not in use and (2) a problem with the O<sub>2</sub> sensor from another analyzer. Both these problems were resolved by returning the instruments to the factory for repair. The initial unreliability of the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer may reflect the fact that this analyzer had been developed by the manufacturer as a prototype over 4 years earlier for our laboratory evaluation and had never been transitioned into a company product. Thus, the manufacturer had no recent experience with constructing these units.

Another problem occurred with the TVAs in which the hydrogen flame of the FID sensor often went out when clothing or a hand brushed against the exterior vent where the sample gas exits the instrument. The instruments were returned to the manufacturer where the flows were re-adjusted to correct this problem. It is not known whether the buyout of Foxboro Co., the previous manufacturer of the TVA, by Thermo Environmental Instruments, Inc., and the incorporation of the Foxboro product line into that of the new company were in any way responsible for the flameout problem.

## MODIFICATIONS TO ORIGINAL SCREENING PROCEDURES

1. During preparation for the on-site evaluation, the vane flowmeter on the aerosol monitor failed to respond adequately to low flows. Consequently, this flowmeter was replaced with a rotameter type flowmeter with a nominal range of 0 to 100 ml/min air (part# GF-5321-2009, 65 mm, 0-120 ml/min air; Gilmont Industries, Barrington, IL). The installation of the rotameter required some minor modifications including the addition of 1/8 inch stainless steel tubing to connect the new flowmeter (see **Figure 1**).
2. At the beginning of the on-site evaluation, the ball valve on the air-sampler that controlled the delivery of sample air to the analyzers was replaced with a stainless steel bonnet needle valve (part# SS-3NRF4; Swagelok Co., Solon, OH) that allowed better flow control.
3. Previous laboratory testing had been done at temperatures generally ranging between 19 and 24 °C but did not specifically evaluate the effect of temperature on analyzer performance.<sup>2</sup> Rather, we had assumed that changes in ambient temperature would introduce minimal error into gas measurements taken in the field when analyzers are operated within the manufacturer-recommended temperature ranges and calibrated and used at similar temperatures. Instrument operating temperatures given by the manufacturers are 0 to 40 °C for the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer, 0 to 40 °C for the TVA, and -10 to 50 °C for the DataRAM. Therefore, it was initially planned that during the field evaluation, analyzer calibration would be performed close to where the compressors would be sampled in order to reduce the difference in ambient temperatures during calibration and testing. However, we soon found this to be impractical due to the excessive compressor noise and often inadequate space. Therefore, equipment was subsequently stored and calibrated inside in a hardware shop at NDSTC approximately 100 yards from the compressors, which were in an adjoining semi-enclosed area protected from precipitation and direct sunlight. At MDSU-2, equipment was stored and calibrated inside a hardware shop with a large entry door, commonly left open allowing the outside temperature to affect that of the shop. The compressors at MDSU-2 were outside the building, unprotected from the weather and sun. Consequently, test results reflected these differences in ambient temperatures during instrument calibration and compressor screening.
4. The original data sheet was found cumbersome to use and required additional pages each time the air was screened during the day. To remedy this, the data sheet was changed soon after the start of the field test so that only two pages were required for each compressor for the entire test day.
5. Temporary darkening of the liquid crystal display (LCD) display of the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer was observed when compressors were sampled outside in direct sunlight. To avoid this problem, an instruction was added to the procedures indicating that when using the analyzers in direct sunlight, the instrument displays be covered with

a piece of cardboard (or equivalent), which would be removed only when taking readings.

6. During the original development and evaluation of the O<sub>2</sub>/CO<sub>2</sub>/CO monitor, we conducted testing to determine possible cross sensitivity of the electrochemical CO sensor to VOCs, as this can be a significant problem with these types of sensors. We exposed the analyzers to ~10-20 ppm isobutylene, the VOC used to calibrate the hydrocarbon analyzer, and observed a negligible CO response. Although we did not have any data on whether cross sensitivity would develop or increase over time as the sensor aged, we incorporated the use of a single calibration span gas that included isobutylene into our field-based procedures for both the O<sub>2</sub>/CO<sub>2</sub>/CO monitor and the hydrocarbon analyzer. However, during a routine test in the laboratory toward the end of (and unrelated to) the one-year field evaluation, two of the original O<sub>2</sub>/CO<sub>2</sub>/CO monitors not used in this project were observed to exhibit a substantial CO response (2-10 ppm) when exposed to 10 ppm isobutylene. Each of these two instruments were over four years old, with CO sensors at least one to two years old, and had not recently been serviced by the manufacturer. Consequently, when the field-testing project was completed and all equipment returned to the lab, we retested two of the newer O<sub>2</sub>/CO<sub>2</sub>/CO monitors that had been used in the field test and observed no CO response to isobutylene.

Because we are unaware of any significant manufacturing changes made to these CO sensors during the past few years, we expect that cross sensitivity of the older units had resulted from the aging and deterioration of the VOC filter in the CO sensor. Regardless of the cause, we decided to insert an additional step into our air screening procedures to check for cross sensitivity of the CO sensor despite the expectation that the normal 1-year recommended preventive maintenance service, which includes sensor replacement where necessary, should lessen the chance for this problem to occur. This added step involves supplying a separate 10-20 ppm isobutylene/balance air standard to the O<sub>2</sub>/CO<sub>2</sub>/CO monitor immediately following normal calibration using the combined gas standard; any CO channel response greater than 1 ppm to the isobutylene standard would be considered indicative of cross sensitivity and require corrective action, presumably replacement of the CO sensor.

## TESTING SUMMARY

At MDSU-2, a total of 20 test days were completed over a 10-month period, June 2001 to April 2002, reflecting the fact that few scheduled test days were missed. Five Navy personnel participated in the field test with all but one person participating for at least eight test days. Two people worked together during half the test days while a single person performed the testing on the other days. A total of three compressors were used during the duration of the entire test, although only two compressors were tested each test day as stipulated by the test plan. All three compressors were the same: Quincy model 5120 (Quincy Compressor, Quincy, IL) units, with maximum output pressure of 250 psig ("medium pressure" air compressors or MPACs). Each compressor is used as

part of a fly-away dive system (FADS) designed to be transportable by air to any diving site in the world. All air samples were taken from a valve on the bottom of the volume tank, the identical sampling location for the Diver's Air Sampling Program.

At the NDSTC, a total of 11 test days were completed over a 10-month period, July 2001 to May 2002. The smaller number of test days indicates that personnel were often unavailable to participate in this project due to manpower shortages at the command. This was evident in the fact that for seven of the test days, the same person was the only tester and two people worked together on only two of the test days. A total of three compressors were used during the field test, although with one exception, only one compressor was tested on each test day because of equipment failures. Thus, the evaluation was much more limited at the NDSTC in terms of numbers of test days, personnel, and compressors. All three compressors were the same: Mako model 5436 (CompAir Mako, Ocala, FL) units, with a maximum outlet pressure of 5000 psig, but configured with a maximum working pressure of 3000 psig ("high pressure" air compressors or HPACs). All air samples were taken from a valve on the outlet side of the moisture separator and filter package, which was where samples were taken for the Diver's Air Sampling Program.

At MDSU-2, ambient temperatures ranged from 6 to 35 °C at the calibration site and -1 to 37 °C where compressors were tested. At the NDSTC, the ambient temperature range was 19 to 29 °C for calibration and 17 to 31 °C for the compressors. The range in calibration and test temperatures for each test day is plotted in **Figure 2**; no temperatures were recorded for the first 2 test days at MDSU-2 so these data are missing from the figure. The lower temperatures and greater deviation between calibration and test temperatures at MDSU-2 reflect the colder climate and the fact that the compressors at MDSU-2 were located outside the building, unprotected from the weather and sun. With the exception of one day at MDSU-2 (a day with a temperature of -1 °C), ambient temperatures during calibration and testing fell within the 0 to 40 °C range that meets the manufacturers' recommendations for operating temperatures for all three instruments.

## **GAS ANALYSIS VARIABILITY AND ACCURACY**

### Precision

Precision, or short-term variability, describes the short-term stability of instrument readings, regardless of the correctness (or accuracy) of these measurements. Defining precision is an important first step in this testing, as within-day variability and accuracy will both be affected by short-term changes in measurements.

Precision is reported as the range of lowest and highest values about the mean and is based on the five measurements taken over a less than 10 min period at the beginning of the test day. Precision may be affected by the ambient temperature at which the repeated measurements are taken, but should not be affected by the difference

between the calibration and testing temperature, although this temperature difference may affect accuracy.

These values are calculated separately for each compressor on each test day, with each set of values representing one "test" as plotted in **Figures 3-5** for O<sub>2</sub>, CO<sub>2</sub>, and the TVA. Data from 40 tests from MDSU-2 are displayed based on 2 compressors tested on each of 20 test days, but only 12 tests are displayed from NDSTC because, with one exception, only 1 compressor was tested on each of the 11 test days. The early gap in the TVA plots (**Figure 5**) reflects missing data.

The following precision values are the grand means calculated from the average and range for each of the 40 tests at MDSU and 12 tests at NDSTC:

O<sub>2</sub>, 21.0%, 20.8 to 21.1%, MDSU-2  
21.0%, 20.9 to 21.2%, NDSTC

CO<sub>2</sub>, 370 ppm, 360 to 390 ppm, MDSU-2  
360 ppm, 330 to 400 ppm, NDSTC

TVA (without charcoal – with charcoal), -0.3 ppm, -0.5 to -0.2 ppm, MDSU-2  
-0.2 ppm, -0.3 to -0.1 ppm, NDSTC

The plots in **Figures 3-5** generally show precision of approximately  $\pm 0.1\%$  O<sub>2</sub>,  $\pm 10$  ppm CO<sub>2</sub>, and  $\pm 0.1$  ppm VOCs, which for O<sub>2</sub> and CO<sub>2</sub> is equivalent to the resolution of the analyzer display, and agree with the grand means, as expected. Although the display of the TVA is  $\pm 0.01$  ppm VOCs and TVA values were recorded in the field as such, all TVA data have been rounded off to the nearest 0.1 ppm. This rounding off eliminates the extra decimal place, which experience (and these data) have shown is meaningless.

The TVA values shown above are the methane-free estimates of the level of hydrocarbons, which are the differences between the non-charcoal and charcoal readings. Their relatively small, negative values reflect the fact that the charcoal readings were always slightly higher than the non-charcoal reading (see **Figure 8**, described below under Within-day Variability). This difference in values is unexpected as the charcoal generally removes all VOCs except methane and should therefore reduce the TVA readings. However, this anomaly has been seen previously in other situations, where the sample air is very clean and the charcoal recently changed, and appears to result from a minor VOC load in the fresh charcoal. A decline in the "fresh charcoal reading" commonly occurs over time (often several days, depending on the amount of instrument use) as air is drawn through the charcoal and apparently removes the residual VOCs, so that the methane-free level moves closer to or above zero. This problem could be addressed by changing the charcoal on a less frequent schedule, than on a daily one that was used in this testing, as the life of charcoal when sampling relatively clean air can extend from weeks to months. However, in our opinion, TVA readings < 1 ppm should be considered "in the noise" for applications such as diving

air, at least partly because of the considerable amount of hardware commonly found upstream from the sample point. This hardware, including piping, filters, and valves, should be expected potentially to add and/or subtract trace amounts of volatile contaminants to/from the air as it flows from the compressor, thus preventing reliable sampling of VOCs at levels < 1 ppm.

The precision values for CO and aerosols are not presented as most measurements of these two components were equal to or near 0 ppm or 0 mg/m<sup>3</sup>, making any precision calculations not meaningful.

#### Within-day Variability

As with the precision data, the variability within the test day is reported as the range of lowest and highest values about the mean. Here, the calculations are based on the four measurements made approximately every two hours over a six-hour period, using only the first value of the series of five repeated measurements done at the beginning of the test day. Variability within the day will be affected by recalibration prior to each two-hour measurement, as well as by changes in the ambient temperature where the calibration is done and where the compressors are tested. The variability will also reflect any change in the constituents of the compressor discharge air although for this test we assumed this change was minimal.

Within-day variability is also calculated separately for each compressor on each test day, with each set of values representing one "test" as plotted in **Figures 6-7** for O<sub>2</sub>, and CO<sub>2</sub>. For the TVA, the three daily means (with and without charcoal), and the difference between these two readings are plotted in **Figure 8**. The data show the relatively low values of the TVA readings, with the charcoal reading always slightly higher than the non-charcoal reading. Consequently, the methane-free estimate, which is the difference between the non-charcoal and charcoal reading, is always slightly negative.

The following values for within-day variability are the grand means calculated from the average and range for each of the 40 tests at MDSU and the 12 tests at NDSTC:

O<sub>2</sub>, 20.9%, 20.7 to 21.1%, MDSU-2  
21.0%, 20.8 to 21.2%, NDSTC

CO<sub>2</sub>, 380 ppm, 350 to 430 ppm, MDSU-2  
420 ppm, 350 to 520 ppm, NDSTC

TVA (without charcoal – with charcoal), -0.3 ppm, -0.5 to -0.1 ppm, MDSU-2  
-0.2 ppm, -0.3 to -0.1 ppm, NDSTC

Again, the values for CO and aerosols are not presented.



These ranges about the means are slightly greater than those presented earlier for precision as would be expected. Likewise, the individual ranges for O<sub>2</sub> and CO<sub>2</sub> for each test day (**Figures 6-7**) are greater than those for precision (**Figures 3-4**). This is expected, as the factors mentioned above introduce additional variability into the measurements over the day.

### Accuracy

At both test sites, field measurements of O<sub>2</sub> generally agreed to within 0.5% of the laboratory value; those for CO<sub>2</sub> agreed to within 100 ppm of the laboratory value (**Figures 9-10**). This level of accuracy was encouraging considering the number of potential errors associated with these tests, including those associated with collection of gas in the field and analysis in the laboratory, and those associated with the temperature differences during calibration and compressor screening. However, the value of these accuracy tests was limited due to the relatively normal levels of O<sub>2</sub> and CO<sub>2</sub> in all the samples. Nevertheless, we expect CO<sub>2</sub> accuracy to be at least as good as this at the 1000 ppm limit because calibration is performed at the limit. The very low levels of CO and VOCs, measured in the field and confirmed in the laboratory, also prevented accuracy testing at higher levels, where concern about air purity would occur.

As discussed earlier, air samples were also to be taken by on-site personnel when unusual readings with the portable analyzers were observed or an objectionable odor detected. No such situations were reported so no additional air samples were taken.

### **RELIABILITY OF TEST EQUIPMENT**

Following resolution of the problems with the analyzers during the first few test days, all the instruments generally functioned reliably and without any obvious problems in terms of easy startup, calibration, and sample measurement. Beyond these basic observations, the variability and accuracy data are probably the best indices of the reliability of the equipment.

### **TRAINING EFFECTIVENESS**

Training over three consecutive test days during a four-week period was generally adequate to bring inexperienced personnel to a level where they felt comfortable performing the procedures alone. Although the actual procedures are not particularly difficult, there are many different steps, and the experience of screening air multiple times over the course of the day undoubtedly helps to gain competence. Despite expected differences among the trainees, it's probably wise to assume that at least several days of hands-on training and testing of air, spread over a week or more for reinforcement, is necessary to bring new people into any testing program in the field. Such a training period would help ensure the desired reliability of any measurements made by relatively inexperienced persons.

Under actual operational settings, training of new personnel might commonly default to working with the current tester designated by the command, as he/she performs the routine six-month screening of diving compressors. Consequently, at commands with only a few compressors, training may be so infrequent that few testers ever reach an adequate level of expertise to ensure reliable measurements. At such locations, it might be necessary to define and mandate specific training requirements prior to use of our field-based procedures for actual compressor screening. However, at such low-use sites, the advantage of these procedures may not outweigh the cost of procurement, maintenance, and repair of the testing equipment. Certainly, these issues should be considered in any decision about transition of these procedures to the fleet.

### SUMMARY AND FINAL CONCLUSIONS

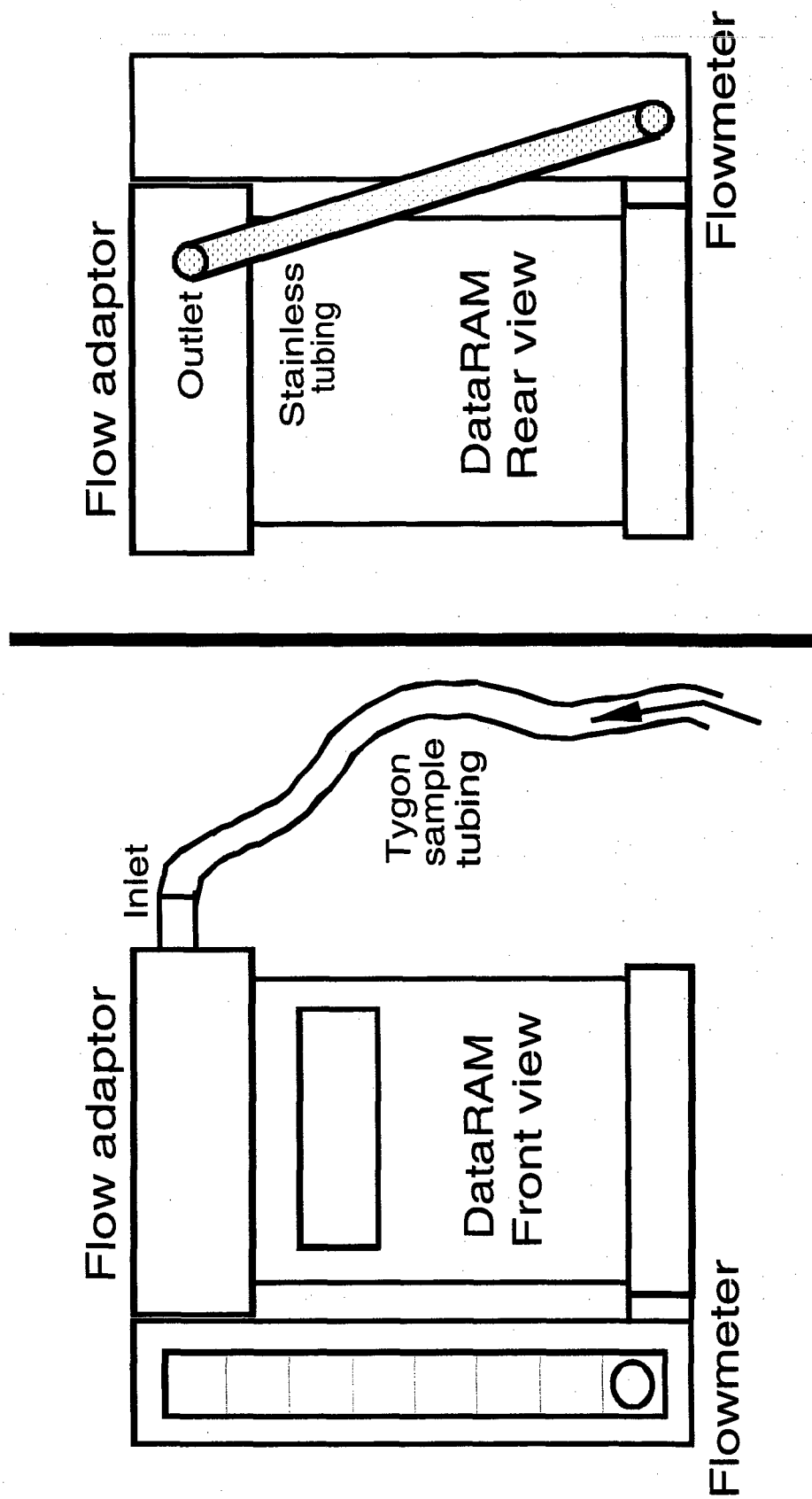
1. Although there are no official U.S. Navy performance requirements for screening diver's air in the field, these procedures, as evaluated previously in the laboratory and now during this one-year field test, should meet the need for reliable field screening.
2. Use of these procedures should be limited to ambient temperatures between 0 and 40 °C to remain within the operating range recommended by the three instrument manufacturers.
3. Reliability of test equipment in the field appeared good once startup problems were resolved. This experience suggests that any transition of these procedures should at least initially include a preliminary check of performance of the test equipment that is procured prior to delivery to the fleet.
4. The successful transition of these procedures will be highly dependent on an adequate training program.
5. The recommended field-based procedures for screening diver's air are given in **Appendix B**. This version includes all the changes made during the on-site evaluation and the check for cross sensitivity to VOCs by the CO sensor added following the completion of this project.
6. In response to changing fleet needs (e.g., partly related to recent salvage diving in fuel-laden water), new tasking from NAVSEA (00C) has redirected current NEDU efforts to focus on testing and evaluating an on-line gas monitor for diving air compressors. This new work relies partly on the results and experience gained from this evaluation of our field-based procedures. We also expect that these field-based screening procedures will be invaluable in evaluating and troubleshooting the performance of any future on-line monitor candidates in the field.

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9. Thermo Environmental Instruments, Inc., *TVA 1000: Response Factors*, P/N 50039, 2000.

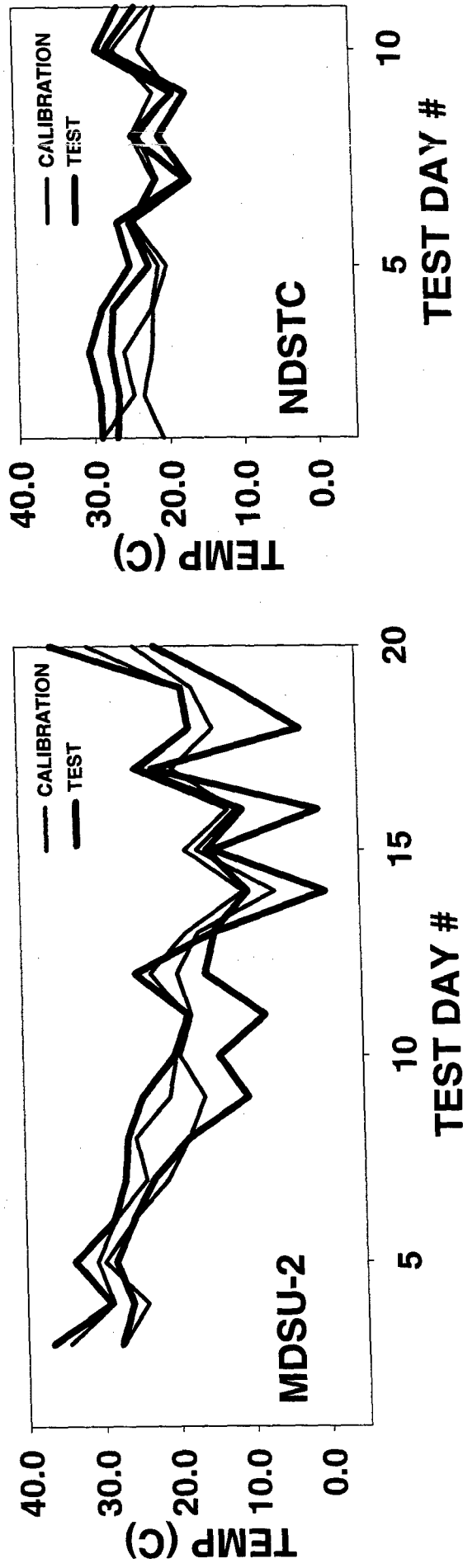
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**Figure 1. DataRAM setup with flowmeter.**



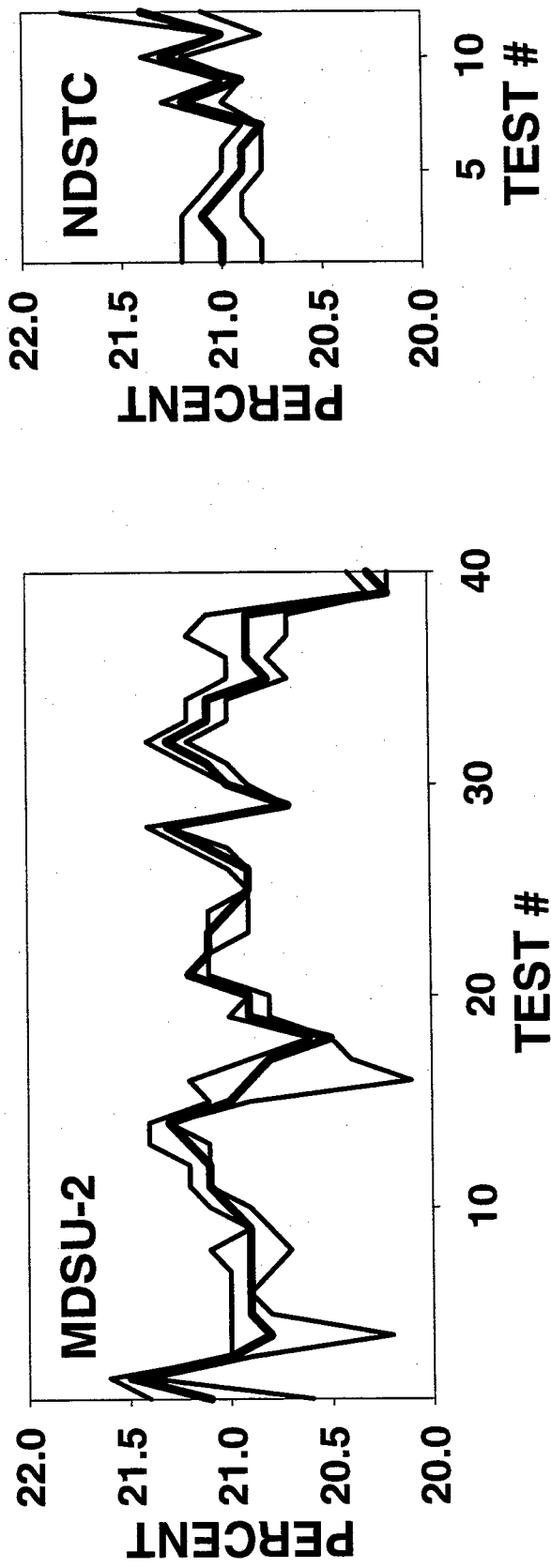
**Figure 2. Range in ambient temperatures.**

Lowest and highest temperatures recorded during instrument calibration and compressor testing for each test day.



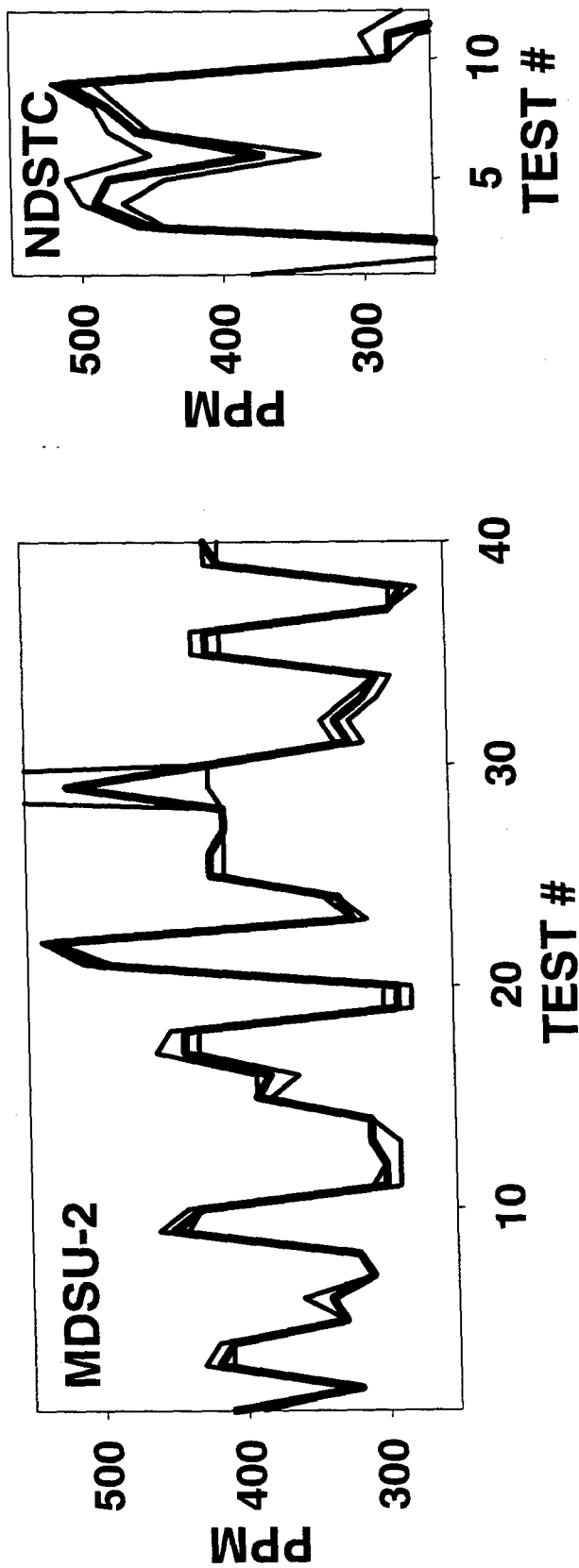
**Figure 3. Precision: O<sub>2</sub>.**

Mean (thick line), lowest, and highest values plotted, based on 5 repeated compressor measurements taken over a less than 10-min period at the beginning of the day. One set of values is plotted separately for each compressor for each test day, representing 1 "test".



**Figure 4. Precision: CO<sub>2</sub>.**

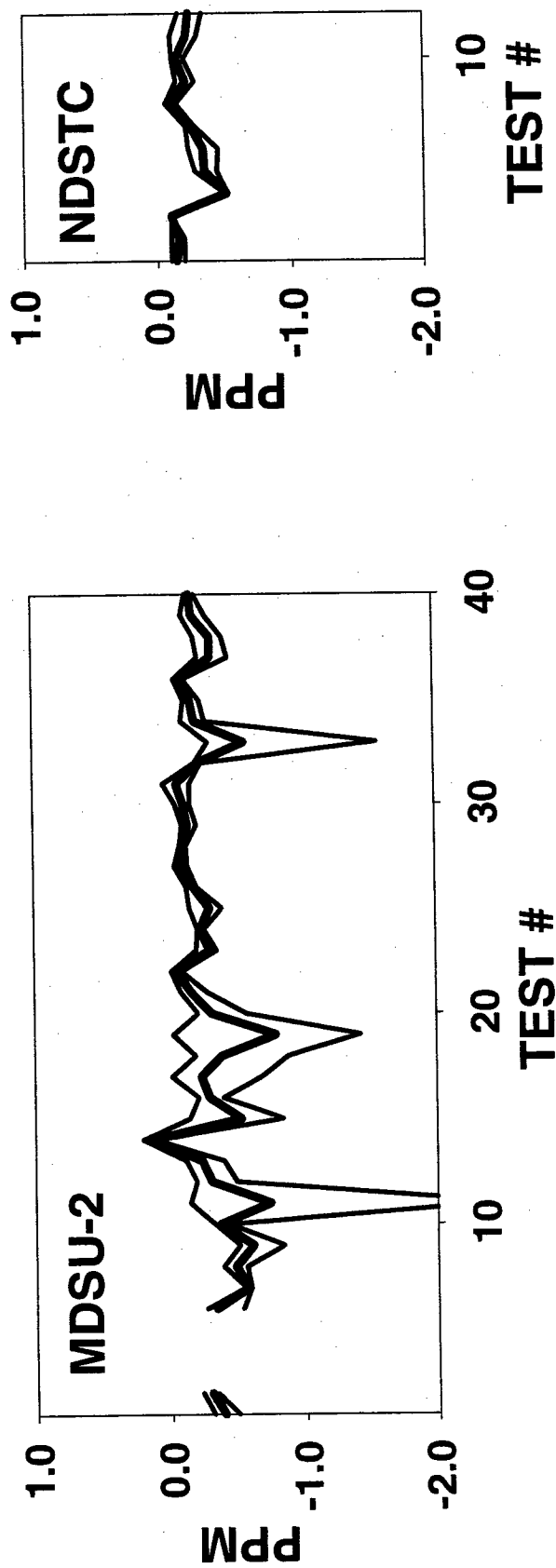
Mean (thick line), lowest, and highest values plotted, based on 5 repeated compressor measurements taken over a less than 10-min period at the beginning of the day. One set of values is plotted separately for each compressor for each test day, representing 1 "test".





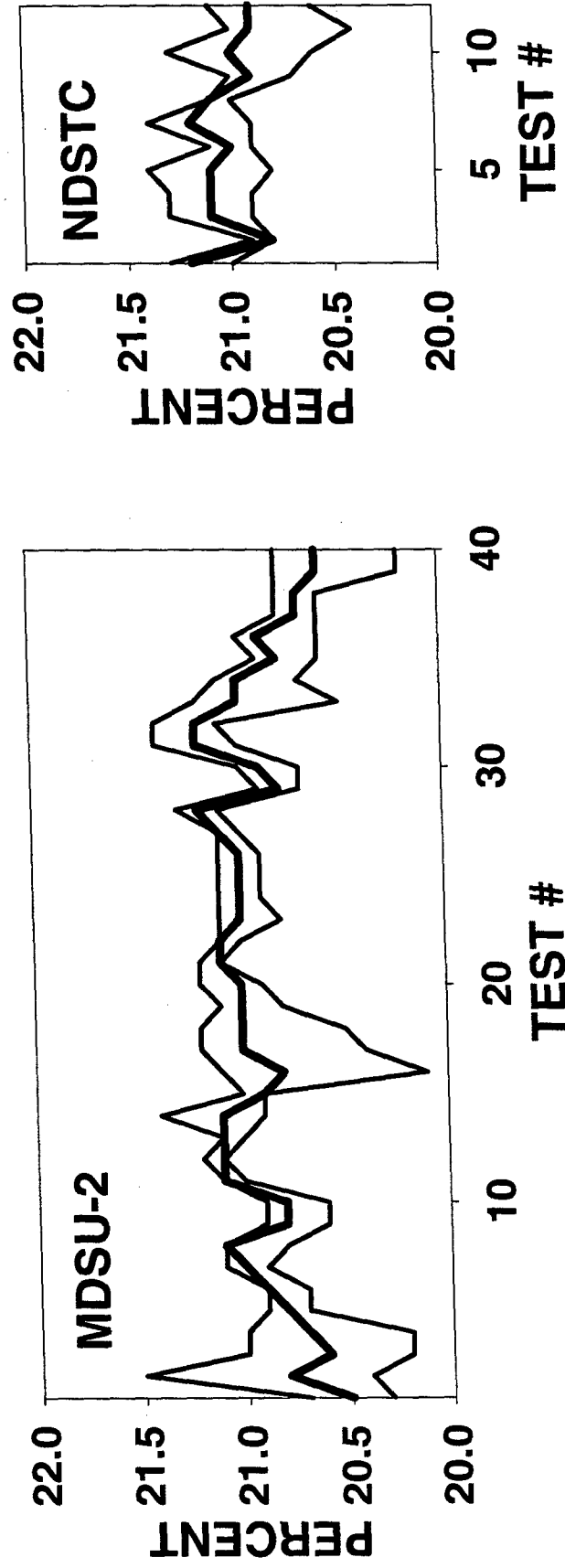
**Figure 5. Precision: TVA.**

Mean (thick line), lowest, and highest values plotted, based on 5 repeated compressor measurements taken over a less than 10-min period at the beginning of the day. One set of values is plotted separately for each compressor for each test day, representing 1 "test".



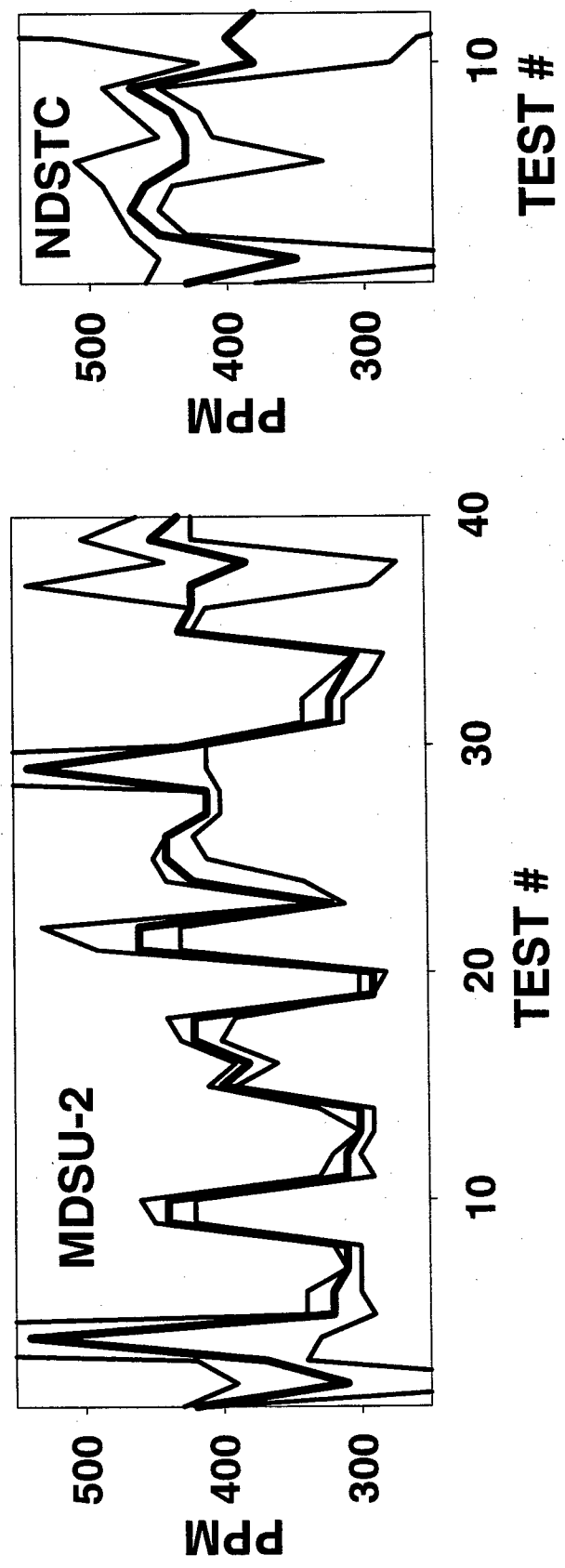
**Figure 6. Within-day variability: O<sub>2</sub>.**

Mean (thick line), lowest, and highest values plotted, based on 4 measurements, one taken every 2 hours over a 6-hour period. One set of values is plotted separately for each compressor for each test day, representing 1 "test".



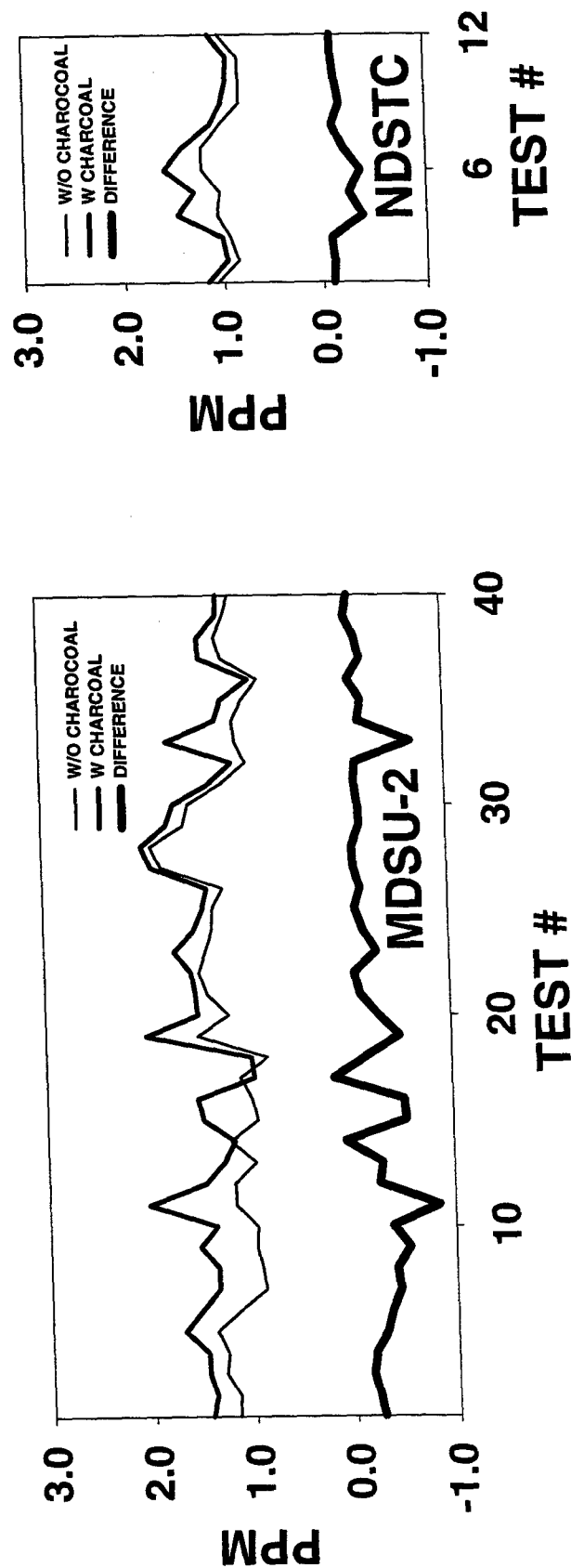
**Figure 7. Within-day variability: CO<sub>2</sub>.**

Mean (thick line), lowest, and highest values plotted, based on 4 measurements, one taken every 2 hours over a 6-hour period. One set of values is plotted separately for each compressor for each test day, representing 1 "test".



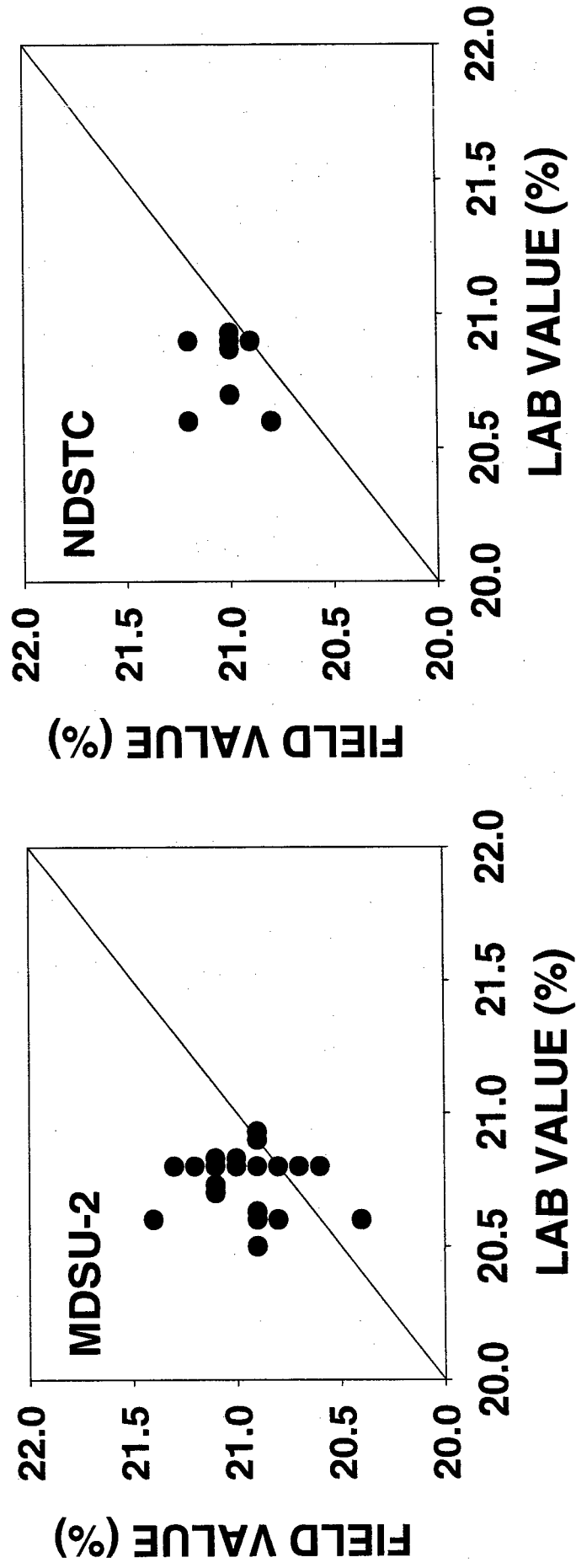
**Figure 8. Daily TVA measurements.**

Daily mean values for the 3 TVA measurements (with and without charcoal, and the difference between these 2 readings). One set of values is plotted separately for each compressor on each test day, representing 1 "test". These data show the relatively low values of the TVA readings, with the charcoal reading always slightly higher than the non-charcoal reading. Consequently, as discussed in the text above, the methane-free estimate, which is the difference between the non-charcoal and charcoal reading, is slightly negative.



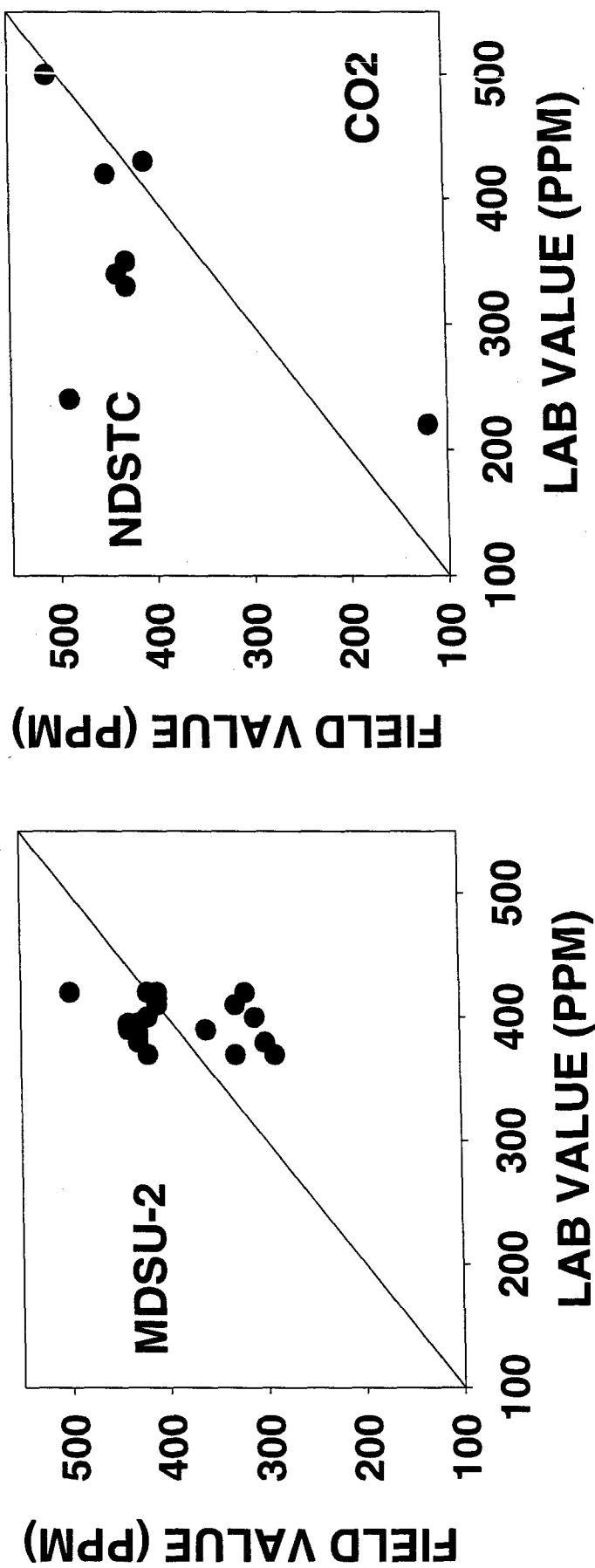
**Figure 9. Accuracy: O<sub>2</sub>.**

Field measurements of O<sub>2</sub> generally agreed to within 0.5% of the laboratory value.



**Figure 10. Accuracy: CO<sub>2</sub>.**

With a few exceptions, field measurements of CO<sub>2</sub> generally agreed to within 100 ppm of the laboratory value.



# APPENDIX A

## Air Sampling Data Sheet (rev 10/26/01) – used during on-site evaluation

Date: \_\_\_\_\_ Facility: \_\_\_\_\_ Person(s) Sampling: \_\_\_\_\_

Compressor make & s/n: \_\_\_\_\_ Sample Site (valve or fitting #): \_\_\_\_\_

Compressor History (recent trouble or service, if any): \_\_\_\_\_

Weather conditions (if outside): \_\_\_\_\_

Notes (use back for additional): \_\_\_\_\_

Gas Cylinder Info:			Cal Gas Concentrations			
H <sub>2</sub> s/n	N <sub>2</sub> s/n	Cal Gas s/n	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Isobutylene ppm

Analyzer Info:				
Set	Geotech S/N	DataRam S/N	TVA S/N	TVA Ignition Time

TEST 1:	Geotech			DataRAM	TVA	CAL Area Temp
Calibration	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Zeroed	Isobutylene ppm	
Time Calibrated						COMP Area Temp
Post-Cal Check						

Compressor	Geotech			Data Ram MG/M <sup>3</sup>		
Readings	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Max "Conc"	"Conc" * 0.5 oil mist corr.	Time
Rep 1						
Rep 2						
Rep 3						
Rep 4						
Rep 5						

	TVA (neg=0)		Adjusted Reading	Methane corr.		Odor?
Readings	1) ppm w/o Char.	2) ppm w/ Char.	(1) - (2) (neg=0)	Adj * 1.5 (neg=0)	Time	Y or N
Rep 1						
Rep 2						
Rep 3						
Rep 4						
Rep 5						

Date: \_\_\_\_\_ Facility: \_\_\_\_\_ Compressor make & s/n: \_\_\_\_\_

<b>TEST 2</b>	<b>Geotech</b>			<b>DataRAM</b>	<b>TVA</b>	<b>CAL Area Temp</b>	
<b>Calibration</b>	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Zeroed	Isobutylene ppm		
<b>Time Calibrated</b>						<b>COMP Area Temp</b>	
<b>Post-Cal Check</b>							
	<b>Geotech</b>			<b>Data Ram MG/M<sup>3</sup></b>			
<b>Compressor</b>	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Max "Conc"	"Conc" * 0.5 oil mist corr.	Time	
<b>Readings</b>							
	<b>TVA (neg=0)</b>		<b>Adjusted Reading</b>		<b>Methane corr.</b>		<b>Odor?</b>
	1) ppm w/o Char.	2) ppm w/ Char.	(1) - (2)	(neg=0)	Adj * 1.5 (neg=0)	Time	Y or N
<b>Readings</b>							

<b>TEST 3</b>	<b>Geotech</b>			<b>DataRAM</b>	<b>TVA</b>	<b>CAL Area Temp</b>	
<b>Calibration</b>	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Zeroed	Isobutylene ppm		
<b>Time Calibrated</b>						<b>COMP Area Temp</b>	
<b>Post-Cal Check</b>							
	<b>Geotech</b>			<b>Data Ram MG/M<sup>3</sup></b>			
<b>Compressor</b>	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Max "Conc"	"Conc" * 0.5 oil mist corr.	Time	
<b>Readings</b>							
	<b>TVA (neg=0)</b>		<b>Adjusted Reading</b>		<b>Methane corr.</b>		<b>Odor?</b>
	1) ppm w/o Char.	2) ppm w/ Char.	(1) - (2)	(neg=0)	Adj * 1.5 (neg=0)	Time	Y or N
<b>Readings</b>							



Date: \_\_\_\_\_ Facility: \_\_\_\_\_ Compressor make & s/n: \_\_\_\_\_

<b>TEST 4:</b>	<b>Geotech</b>			<b>DataRAM</b>	<b>TVA</b>	<b>CAL Area Temp</b>	
<b>Calibration</b>	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Zeroed	Isobutylene ppm		
Time Calibrated						<b>COMP Area Temp</b>	
Post-Cal Check							
	<b>Geotech</b>			<b>Data Ram MG/M<sup>3</sup></b>			
<b>Compressor</b>	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Max "Conc"	"Conc" * 0.5 oil mist corr.	Time	
Readings							
	<b>TVA (neg=0)</b>		<b>Adjusted Reading</b>	<b>Methane corr.</b>		<b>Odor?</b>	
	1) ppm w/o Char.	2) ppm w/ Char.	(1) - (2) (neg=0)	Adj * 1.5 (neg=0)	Time	Y or N	
Readings							
<b>High-Pressure Air Samples (if collected)</b>			<b>Type of Sample (check one)</b>				
	Cylinder #	Time Collected	Normal 4 week		Unusual values or odor (specify)		
Sample 1							
Dup. Sample 2							

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## **APPENDIX B**

### **FIELD-BASED PROCEDURES FOR SCREENING DIVER'S AIR**

#### **INTRODUCTION**

1. Appropriate hearing and eye protective devices should be worn during this testing.
2. Postpone the testing to another day if weather is inclement; do not expose equipment to weather (e.g., high wind, precipitation) that may damage it.
3. Air will be screened from the compressor, at the sampling location given in the U.S. Navy Diving Manual, using the air-sampler apparatus and the 3 portable analyzers:  
(a) Geotechnical O<sub>2</sub>/CO<sub>2</sub>/CO analyzer, (b) Foxboro Toxic Vapor Analyzer (TVA), and  
(c) MIE Personal/DataRAM aerosol monitor.
4. All data and sampling information will be recorded on the data sheet given at the end of these procedures.

#### **BATTERY CHECKS AND REFILLING OF TVA H<sub>2</sub> CYLINDERS (done the day before testing)**

Both the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and the TVA are normally operated from their self-contained NiCad batteries. These batteries are recharged using chargers that plug into 110 volt line current. Ideally, NiCad batteries should be fully discharged and recharged during use rather than continually topped off without a full discharge. However, a full discharge followed by a recharge probably will not be possible and the best approach is to check the battery (as described below) the day before to allow time for 24-hour charging if the battery is low. Complete recharging should provide 12 hours of usage for the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and at least 8 hours of operation for the TVA.

The Personal/DataRam aerosol monitor is normally operated from its self-contained non-rechargeable 9 V alkaline battery which is replaced when necessary. A fresh battery should provide a minimum of 20 hours of continuous operation.

1. Ensure that the batteries of the 2 O<sub>2</sub>/CO<sub>2</sub>/CO analyzers are fully charged and recharge if necessary.
  - a. Disconnect analyzer from charger.
  - b. Turn on analyzer by pressing the red key. The LCD will show the company name, model, and information on key functions. Press the "0" key to exit that screen.
  - c. Press "1" for General Utilities.

- d. Press "4" to read the available battery capacity. If there is insufficient charge (< 50%), the analyzer should be charged by attaching cord from charger and leaving overnight. Turn analyzer off by pressing the red key.
2. Ensure that the batteries of the 2 TVAs are fully charged and recharge if necessary.
  - a. Disconnect TVA from charger.
  - b. Press the "ON" key and wait for the beep and "Main Menu" to appear on the display.
  - c. At the Main Menu, select "Info." Press the down arrow to cycle through "Info" and check the battery. Fully charged batteries should read approximately 8 volts. If the battery is less than 7 volts, it should be charged by attaching cord from charger and leaving overnight. Turn TVA off by pressing the "OFF" key.
3. Check the non-rechargeable batteries of the 2 DataRAMs and replace if necessary.
  - a. Turn the DataRAM on by pressing the "ON/OFF" button. Press the "NEXT" button 6 times until the battery status is displayed. If the remaining battery charge is < 60%, replace battery after turning DataRAM off by pressing "ON/OFF" followed by "ENTER".
  - b. Battery replacement. Loosen lower nut on flowmeter line, remove hex screw on bottom of DataRAM, and pull base with flowmeter off. Loosen battery cover screw on bottom of DataRAM and remove battery cover. Replace battery taking care to position battery with negative connector toward outside edge of DataRAM. Re-assemble DataRAM.
  - c. If battery was replaced, turn the DataRAM back on and repeat battery check to confirm new battery is fully charged.
4. Refill the TVA H<sub>2</sub> cylinders
  - a. Attach H<sub>2</sub> refilling assembly (with its valve "OFF") to the H<sub>2</sub> supply cylinder and pressure cycle 3 times to remove all ambient air. Leave refilling valve in "OFF" position.
  - b. Attach TVA cylinder (left-hand thread) – do not overtighten.
  - c. Open H<sub>2</sub> supply valve and move refilling valve to "FILL".
  - d. Wait for the TVA cylinder to fill, which may take 2 to 3 minutes because of flow restriction in the line. Do not fill TVA cylinder to a pressure greater than 2,200 psig to avoid activating the pressure relief and causing irreversible damage to the cylinder.

- e. Close refilling valve and remove TVA cylinder.
- f. Repeat with second cylinder if necessary.
- g. Close H<sub>2</sub> supply valve and remove refilling assembly.

## **AIR SCREENING**

1. Complete the top information section of the data sheet.
2. Calibration is probably best done away from the compressor area to avoid noise and allow adequate space. If the air temperature where analyzers will be calibrated is outside the temperature range at which the analyzers were stored, the unpacked analyzers should be allowed to equilibrate at least 1 hour at the calibration location before calibration and use.
3. Prepare the analyzers for use, according to instructions below while completing the calibration section of the data sheet.

## **Analyzer startup and calibration**

1. A battery check and calibration (or zeroing in the case of the DataRAM) must be done once prior to each day's use of all 3 analyzers.
2. Locate the zero N<sub>2</sub> and calibration gas cylinders. The calibration mixture is: ~21% O<sub>2</sub>, ~1,000 ppm CO<sub>2</sub>, ~20 ppm CO, ~10 ppm isobutylene, in balance N<sub>2</sub>. (NOTE: The isobutylene calibration gas is completely non-toxic and has a long history of safe use.) Record calibration gas information on the data sheet.
3. Install regulators on the zero N<sub>2</sub> and calibration gas cylinders and pressure cycle each regulator 3 times to remove all ambient air. Dial in a delivery pressure of several psig. Leave gas cylinder valves open but close regulator delivery valves so gas is not flowing.
4. Attach a new plastic stopcock on the end of both regulators and a new 5 ml syringe barrel (or equivalent) on the stopcock of the calibration gas (see **Figure B-1**). Install the branched sampling tubing on the free port of both stopcocks.
5. TVA startup.
  - a. Disconnect TVA from charger.
  - b. Attach the TVA probe and electrical cable to the TVA. Ensure that the normal sampler (the smaller of the 2 types of samplers) is installed on the end of the

probe so that the charcoal filter (the larger sampler) can be re-loaded as described below.

- c. Check the pressure of the TVA H<sub>2</sub> cylinder located on the left side of the analyzer. Maximum pressure is 2,300 psig. The TVA uses ~150 psi of H<sub>2</sub> per hour. If pressure is low, replace H<sub>2</sub> cylinder with a fully charged cylinder (left-hand thread).
- d. Turn the red H<sub>2</sub> supply valve located on the back side of the analyzer to "ON." Press the "ON" key and wait for the beep and "Main Menu" to appear on the display.
- e. Battery check. Batteries should be checked with the charger disconnected. At the Main Menu, select "Info." Press the down arrow to cycle through "Info" and check the battery. Fully charged batteries should read approximately 8 volts. If the battery is less than 7 volts, batteries should be charged. The instrument may be used with line power via the battery charger if necessary.
- f. After turning on the H<sub>2</sub>, ensure that 2 to 3 minutes have elapsed to allow the H<sub>2</sub> to fill the FID chamber, before proceeding to the next step.
- g. Press the "EXIT" key and then select "Run." The pump will then start (confirm pump noise) and after approximately 10 seconds, auto ignition will occur. If the pump does not start, it will need to be fixed. If the FID lights, the TVA will automatically go into the run mode with the FID reading displayed. The FID value (on the display of either the instrument or the sampling probe) should be varying and other than zero.
- h. If the FID did not light, a Flameout warning will display. Wait 2 to 3 minutes more and try again to ignite by pressing the "EXIT" key twice and then selecting "Run" again.
- i. If the FID ignites but then goes out anytime afterward, a Flameout warning will appear and the FID will have to be re-ignited.
- j. After lighting the FID, record the ignition time on the data sheet.
- k. Re-load the charcoal filter sampler with fresh charcoal using Teflon tape to reseal the sampler. Then remove the normal sampler and replace it with the charcoal sampler. This will allow conditioning of the charcoal during the warm-up period.
- l. While waiting 30 minutes for the TVA to warm-up before starting its calibration, record with the digital thermometer the ambient air temperature of the site where instruments will be calibrated ("CAL Area Temp").

6. O<sub>2</sub>/CO<sub>2</sub>/CO analyzer.

- a. Disconnect analyzer from charger.
- b. Turn on analyzer by pressing the red key. The LCD will show the company name, model, and information on key functions. Press the "0" key to exit that screen.
- c. Press "1" for General Utilities.
- d. Battery check. Batteries should be checked without the charger connected. Press "4" to read the available battery capacity. If there is insufficient charge (< 50%), the analyzer should be charged. The instrument may be used with line power via the battery charger if necessary.
- e. Press "0" and then "2" (calibrate), "1" (O<sub>2</sub>), "1" (zero). Press "5" to turn on pump; confirm pump is on by pump noise. Analyzer is now measuring O<sub>2</sub>. Allow to warm up for five minutes.
- f. Connect the inlet port of the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer to one branch of the sampling tubing from the zero N<sub>2</sub> cylinder and the stand-alone flowmeter to the other branch (see **Figure B-1**).
- g. Ensure that stopcock is turned to direct flow to sampling tubing. Open the N<sub>2</sub> regulator valve and adjust gas flow so the rotameter ball is midway up the flowmeter.
- h. Wait at least one minute for reading to stabilize. Press "1" (zero level), "0" (exit), "0" (previous menu). O<sub>2</sub> is now zeroed.
- i. Press "3" (CO), "1" (zero). Press "5" to turn on pump and confirm pump is on. Analyzer is now measuring CO.
- j. Confirm that reading is stable. Press "1" (zero level), "0" (exit), "0" (previous menu). CO is now zeroed.
- k. CO<sub>2</sub> does not require zeroing.
- l. Remove analyzer from N<sub>2</sub> tubing. Shut off N<sub>2</sub> gas flow but leave cylinder valve open.
- m. Press "1" (O<sub>2</sub>), "2" (span). Press "5" to turn on pump and confirm pump is on. Analyzer is now measuring O<sub>2</sub>.
- n. Attach analyzer to the calibration gas tubing and adjust flow similarly using the flowmeter.

- o. Wait at least one minute for reading to stabilize. Press "1" (enter gas con) and enter the calibration value (e.g., "0208" for 20.8%). To backspace over an entry mistake, press and hold "0".
- p. Then press "0" (exit), "1" (yes), "0" (exit), "0" (previous menu). O<sub>2</sub> is now calibrated.
- q. Press "2" (CO<sub>2</sub>) and then "5" to turn on pump. Confirm that pump is on. Analyzer is now measuring CO<sub>2</sub>.
- r. Confirm that reading is stable. Press "1" (enter gas con) and enter the calibration concentration (e.g., "1000" for 1000 ppm). Then press "0" (exit), "1" (yes), "0" (exit). CO<sub>2</sub> is now calibrated.
- s. Press "3" (CO), "2" (span). Press "5" to turn on pump and confirm pump is on. Analyzer is now measuring CO.
- t. Confirm that reading is stable. Press "1" (enter gas con) and enter the calibration concentration (e.g., "020" for 20 ppm). Then press "0" (exit), "1" (yes), "0" (exit), "0" (previous menu). CO is now calibrated.
- u. Exit out of calibration to read gas levels by pressing "0", "0" (exit), "2" (read gas levels), "2" (no), "5" (pump on). Confirm pump is on.
- v. When stable, observe readouts of calibration gas. Readings should be within 0.2% O<sub>2</sub>, 40 ppm CO<sub>2</sub>, and 2 ppm CO of calibration values. Repeat calibration (both zero and span) of any of the gases with readings outside of these ranges. If any readings are still outside these ranges after re-calibration, proceed to the next step.
- w. Record time of calibration and analyzer values when sampling calibration gas ("Post-Cal Check") on the data sheet.
- x. Shut off both N<sub>2</sub> and calibration gas flow but leave both cylinder valves open. Remove O<sub>2</sub>/CO<sub>2</sub>/CO analyzer from tubing. Leave analyzer turned on, with pump on and reading gas levels.

## 7. DataRAM aerosol monitor

- a. Prior to each day's use, the battery should be checked and the DataRAM zeroed.
- b. Battery check. Turn the DataRAM on by pressing the "ON/OFF" button. Press the "NEXT" button six times until the battery status is displayed. If the remaining



battery charge is < 60%, replace battery after turning DataRAM off by pressing "ON/OFF" followed by "ENTER".

- c. Battery replacement. Loosen lower nut on flowmeter line, remove hex screw on bottom of DataRAM, and pull off base with flowmeter. Loosen battery cover screw on bottom of DataRAM and remove battery cover. Replace battery taking care to position battery with negative connector toward outside edge of DataRAM. Re-assemble DataRAM.
- d. If battery was replaced, turn the DataRAM back on and repeat battery check to confirm new battery is fully charged.
- e. Turn DataRAM off and ensure that the flow control knob on its flowmeter is completely open.
- f. Connect the end of the hand pump (with filter) to the inlet port (right side) of the DataRAM. This pump includes a filter to deliver particulate-free air to the DataRAM to allow zeroing. Start pumping the hand pump and confirm that the rotameter ball on the outflow jumps with each pump stroke.
- g. After 3 pump strokes, turn the DataRAM on and press "ENTER" to start zeroing; continue slowly pumping (1 stroke every 5 seconds) the hand pump. The screen should display the following: "ZEROING V2.00."
- h. After approximately one minute, the display should read: "CALIBRATION: OK."
- i. If the display reads: "BACKGROUND HIGH," accurate readings can still be taken although the sensor head needs to be cleaned at the earliest opportunity. Contact NEDU for assistance.
- j. Remove the hand pump. Press the "NEXT" key and then "ENTER" to start measuring.
- k. The DataRAM is now measuring the aerosol concentration in the gas in its sensing chamber. The CONC value is the instantaneous concentration which will be used for diver's air. The TWA value is the Time Weighted Average concentration and will not be used.
- l. Record time of zeroing and analyzer reading ("Post-Cal Check") on the data sheet.
- m. Leave DataRAM on.

8. TVA (fill out calibration information on the data sheet).

- a. Confirm that at least 30 min has passed since TVA ignition and that the FID is still lighted.
- b. Ensure that the calibration mode is set to automatic so that the TVA will automatically accept the calibration (rather than require a prompt to accept). To do this, first press the "EXIT" key to reach the Main Menu. Then select "Setup," then "Calib," then "Cfg" (configuration). Press the up arrow twice. Then select "Accept mode" and "Auto" if not already selected. Press "EXIT" to return to the Calibration Menu.
- c. Check the calibration gas concentration currently in TVA memory by first selecting "Span Conc." If the concentration of the isobutylene calibration gas (e.g., 10.50 ppm) is correctly displayed, press "EXIT."
- d. If the calibration concentration is not correct, press "ENTER," enter the concentration of the isobutylene calibration gas (e.g., "1050" for 10.5 ppm), and again press the "ENTER" key.
- e. To zero the FID detector, select "Zero" and then "ENTER."
- f. The charcoal filter sampler should already be on the end of the probe. This filter removes the isobutylene from the calibration gas and provides zero gas to the TVA. The zero N<sub>2</sub> used with the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer above cannot be used to zero the TVA as the FID requires O<sub>2</sub> in the sample gas to support the flame.
- g. Turn the stopcock on the calibration gas regulator to direct flow to the syringe barrel. Open the delivery valve on the regulator and adjust calibration gas flow so that there is noticeable (but not excessive) gas flow exiting the syringe barrel by feel and/or hearing.
- h. Insert the TVA probe halfway into the syringe barrel. Wait 30 seconds and then press "ENTER." Wait approximately 15 seconds until the menu returns. Shut off calibration gas flow. The FID has now been zeroed.
- i. Remove the charcoal filter and replace the normal sampler to prepare to span the TVA.
- j. To span the FID, select "Span" and then "ENTER."
- k. Again adjust calibration gas flow so that there is noticeable (but not excessive) gas flow exiting the syringe barrel. Insert probe into syringe barrel. Wait 30 seconds and press "ENTER." Wait approximately 15 seconds until menu returns. The FID has now been spanned.

- l. Press "EXIT" key twice and then select "Run."
- m. Observe readout with the probe in the calibration gas. The FID reading should be within 0.5 ppm of the calibration value. Repeat calibration if reading is outside of this range. If reading is still outside this range after re-calibration, proceed to the next step.
- n. Record time of calibration and FID reading when sampling calibration gas ("Post-Cal Check") on the data sheet.
- o. Shut off gas flow. If this is the last calibration for the day, close valves on the N<sub>2</sub> and calibration gas cylinders, bleed down, and remove regulators and place them and the sampling tubing inside their storage bags. Otherwise, leave both N<sub>2</sub> and calibration gas cylinder valves open with regulators attached for later use.
- p. Leave TVA in run mode and with normal sampler in probe. FID values are now read off the TVA display or the sampling probe.

### Compressor screening

1. Prior to sampling, each compressor should be operated for at least 10 minutes to warm up. During the warm-up period, blow out the compressor line through the sample site at a highly audible rate to remove any water and to equilibrate the line with the gas. After at least 2 minutes of purging the sample line, ensure that no water (or any liquid) is being blown out by holding a cloth or tissue in the gas stream and checking for wetness with your hand. If a wet spot is noted, continue to vent gas until dry to touch. Close the valve at the sample site to shut off gas flow.
2. Ensure that all 3 valves on the air-sampler are fully closed. Then connect the air-sampler (pressure rated to 5,000 psi) to the sample site using the fittings provided.
3. Attach a new plastic stopcock and new 5 ml syringe barrel (or equivalent) to the air-sampler (**Figure B-2**). The syringe barrel should be installed on side port of the stopcock so that the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and DataRAM aerosol monitor can use the other port for sampling. This will avoid any potential change in oil mist concentration that might occur with a 90-degree turn in the airflow.
4. Attach the branched sampling tubing to the free port of the stopcock where the gas will be sampled with the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and the DataRAM (**Figures B-2 and B-3**). Turn the stopcock so that all flow will be directed to the sampling tubing.
5. Slowly open the valve(s) on the compressor line to deliver pressure to the air-sampler. Once this valve is fully open, slowly fully open the upstream air-sampler valve. After line pressure has equalized, slowly and partially open the downstream side valve on the air-sampler so gas is directed out through the open port at a

clearly audible level, away from the stopcock where the analyzers will sample the gas.

6. Allow gas to purge the air-sampler for at least 2 minutes to equilibrate with the gas and then close the side valve.
7. If the compressors are being sampled outside in direct sunlight, cover the displays of the analyzers with a piece of cardboard (or equivalent) to avoid temporary darkening of the LCD readout.
8. Sample the gas with the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and DataRAM aerosol monitor.
  - a. The O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and DataRAM should already be on and ready to use. Insure that the flow control knob on the DataRAM's flowmeter is completely open.
  - b. Attach the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer to one branch of the sampling tubing and the DataRAM to the other branch (**Figure B-3**).
  - c. Carefully open the downstream valve so the rotameter ball is midway up the DataRAM flowmeter measuring the outflow. Avoid producing an excessive flow that could blow out the tubing and damage the analyzers.
  - d. Wait at least one minute until the readings on the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer are stable and then record measurements on data sheet.
  - e. After 2 minutes, record the CONC value from the DataRAM on the data sheet. Then, multiply the value by the correction factor (0.5) to convert the DataRAM reading to oil mist concentration and record time on data sheet.
  - f. If the calculated oil mist concentration exceeds the limit of 5 mg/m<sup>3</sup>, the air-sampler should be cleaned to U.S. Navy O<sub>2</sub>-use specifications before air is sampled again. The sampling tubing, 3-way stopcock, and syringe barrel should be replaced too.
  - g. Leave both the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and DataRAM turned on but remove them from the sampling tubing (which is left on the air-sampler).
9. Sample the gas with the TVA.
  - a. Turn the stopcock to the syringe barrel and confirm by touch that there is noticeable (but not excessive) gas flow exiting the syringe barrel (**Figure B-2**). Re-adjust flow if necessary. Wait one minute.
  - b. The TVA should already be on and ready to use.

- c. Position the normal sampler (without charcoal) halfway into syringe barrel and wait at least one minute until the reading stabilizes.
  - d. The TVA value is read off the display on either the instrument or the sampling probe, and represents the total hydrocarbon concentration of the air.
  - e. Record measurement on data sheet. If reading is a negative value, record 0.
  - f. Remove the normal sampler and install the charcoal filter, which removes all contaminants except methane from the air.
  - g. Again wait at least one minute until the reading stabilizes and record. Again, if reading is a negative value, record 0. This value represents the methane concentration of the air.
  - h. Calculate the total hydrocarbon concentration (excluding methane) in methane equivalents using the data sheet. Record time on data sheet.
  - i. Leave the TVA turned on and the syringe barrel on the air-sampler.
10. Record the presence of any objectionable odor in the sample gas on the data sheet.

#### **High-pressure air collection (when needed)**

1. Take duplicate air samples from the compressor if (1) unusual readings with any of the portable analyzers are observed or (2) any objectionable odor is detected. If samples are taken, complete the bottom section of the data sheet.
2. Samples should be taken using high-pressure cylinders that have been evacuated and have an internal volume of at least 500 ml to insure an adequate volume of gas for analysis. These cylinders must be suitable for storage of ppm levels of volatile organic compounds for up to 1 month. Such cylinders should have a working pressure rating of at least 1000 psig and will require appropriate fittings and connection hardware to connect to sample site. Cylinders and connection hardware can be obtained from NEDU. These procedures assume that NEDU cylinders are used but can also be adapted to other cylinders.
3. Before proceeding, ensure that the compressor has been warmed up and that purging of the sampling line has been performed as required for the screening procedures.
4. After purging, attach the high-pressure regulator (configured to attach to the sample cylinders; **Figure B-4**) to the sample site to allow filling cylinders with ~200 psig of bank air. Do not use the air-sampler to fill cylinders as this device does not reduce the pressure so the cylinders may be exposed to pressures higher than their pressure rating.

5. Slowly open the valve(s) on the compressor line to pressurize the regulator. Then pressure cycle the regulator 3 times to remove all ambient air.
6. Dial in sufficient delivery pressure (< 25 psig) with the regulator to purge at a highly audible rate for five minutes.
7. Check cylinder valves just prior to use to ensure they have not become opened during transit. Do not use any cylinders that have loose valves and are suspected of having lost vacuum. Take extreme care to avoid exposing cylinders to more than their working pressure rating.
8. Attach the first cylinder to the regulator as gas is flowing. Make the cylinder connection wrench-tight and fully open the downstream valve on the regulator. Then slowly and fully open the cylinder valve closest to the regulator ~1 full turn until the tension on the handle is released (e.g., it should take approximately 10 seconds to complete this full turn of the valve handle). If the handle is turned much beyond this point, the handle will fall off and will have to be screwed back on.
9. After the cylinder valve has been opened, dial in 200 psig, and allow 2 minutes for the cylinder to equilibrate with the upstream pressure. Then close the cylinder valve tightly. Leave gas flow on as the first cylinder is disconnected from the regulator and the second cylinder is attached and filled in similar fashion. Flow should be throttled back during cylinder removal and attachment.
10. After the second cylinder has been disconnected from the regulator, shut off flow at the sample site and disconnect hardware.
11. Shut off compressor.
12. Record on the tag attached to each cylinder:
  - a. Date
  - b. Facility
  - c. Person(s) collecting the samples
  - d. Compressor make/serial #
  - e. Sample site (valve or fitting location or #)
  - f. Cylinder #
  - g. Sample time

and complete the cylinder information on the data sheet.

13. Prior to return of cylinders to NEDU, pack them in the Pelican case by carefully wrapping each cylinder with packing material. Check all cylinder valves for tightness just prior to packing. Include cylinder data sheets. A properly packed Pelican case

should not rattle at all. Secure Pelican case using nylon ties to discourage tampering.

### **Post-testing shutdown**

1. Close the valve(s) on the compressor line. Bleed down, close all air-sampler valves, and remove air-sampler from the compressor line. Shut off compressor or leave running as desired.
2. When finished for the day, turn off the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer by pressing the red key. Press the "ON/OFF" button on the DataRAM and then "ENTER" to turn off. Close the red H<sub>2</sub> supply valve on the TVA and press the "OFF" key.
3. Return all 3 analyzers to their inside storage locations, and, if possible, plug the TVA and O<sub>2</sub>/CO<sub>2</sub>/O<sub>2</sub> analyzer into their battery chargers. Charge them overnight but remove them from chargers after 24 hours and store away in a safe place. Store all other gear in a Pelican case or equivalent.

### **CO SENSOR CROSS SENSITIVITY CHECK**

1. At least once every six months, the O<sub>2</sub>/CO<sub>2</sub>/CO analyzer should be tested, following normal calibration, with a separate 10-20 ppm isobutylene/balance air standard.
2. Any CO channel response greater than 1 ppm to the isobutylene standard requires corrective action, presumably replacement of the CO sensor.

**Figure B-1. Calibration setup for O<sub>2</sub>/CO<sub>2</sub>/CO analyzer and TVA.**

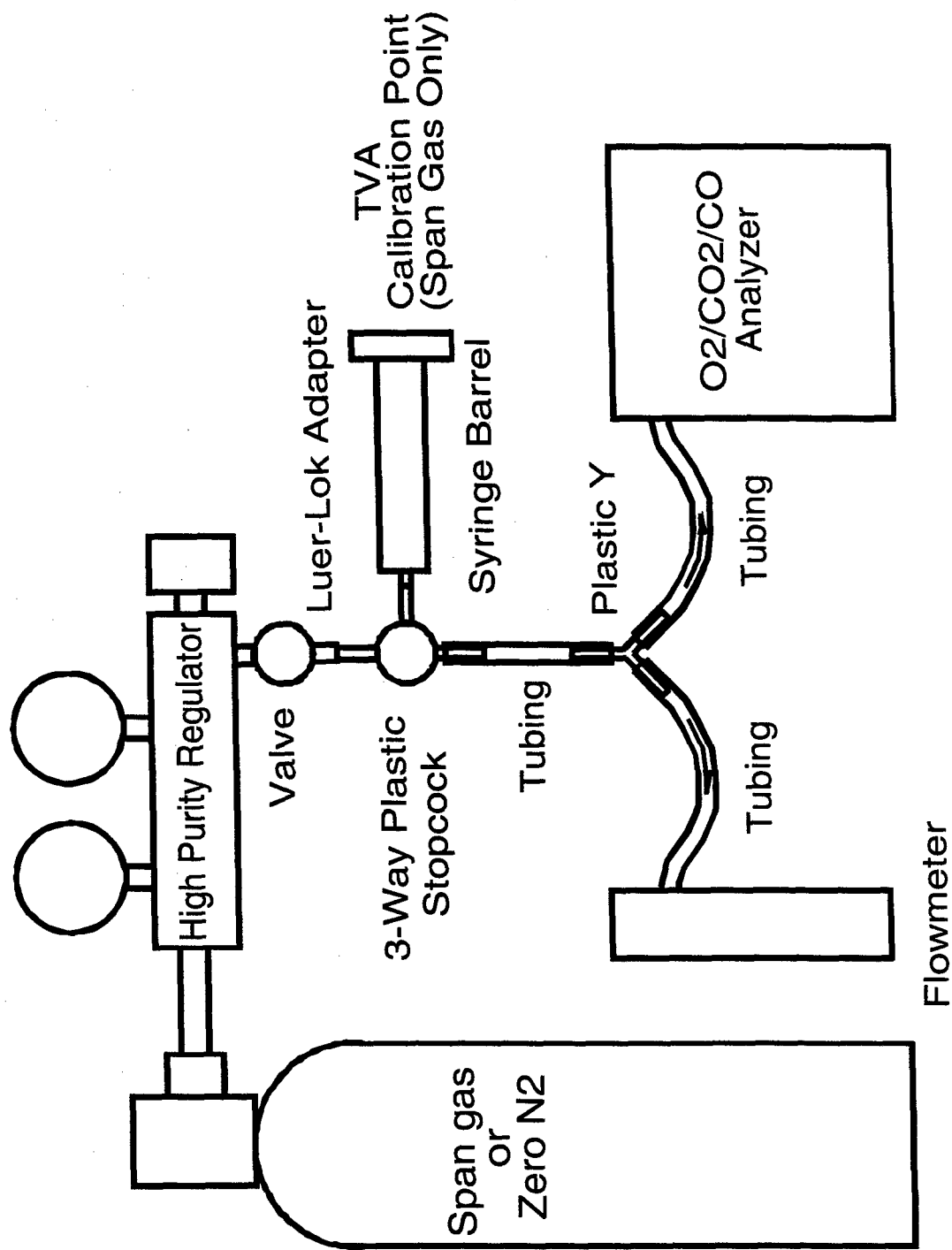
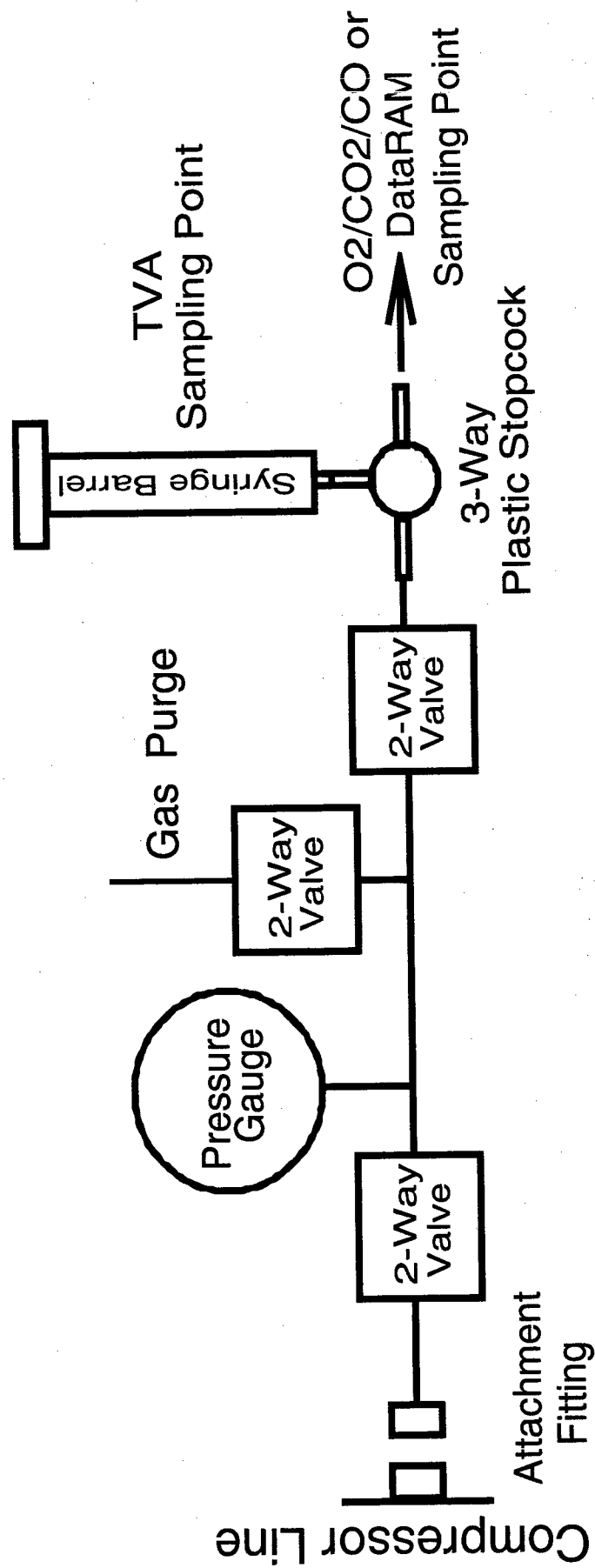
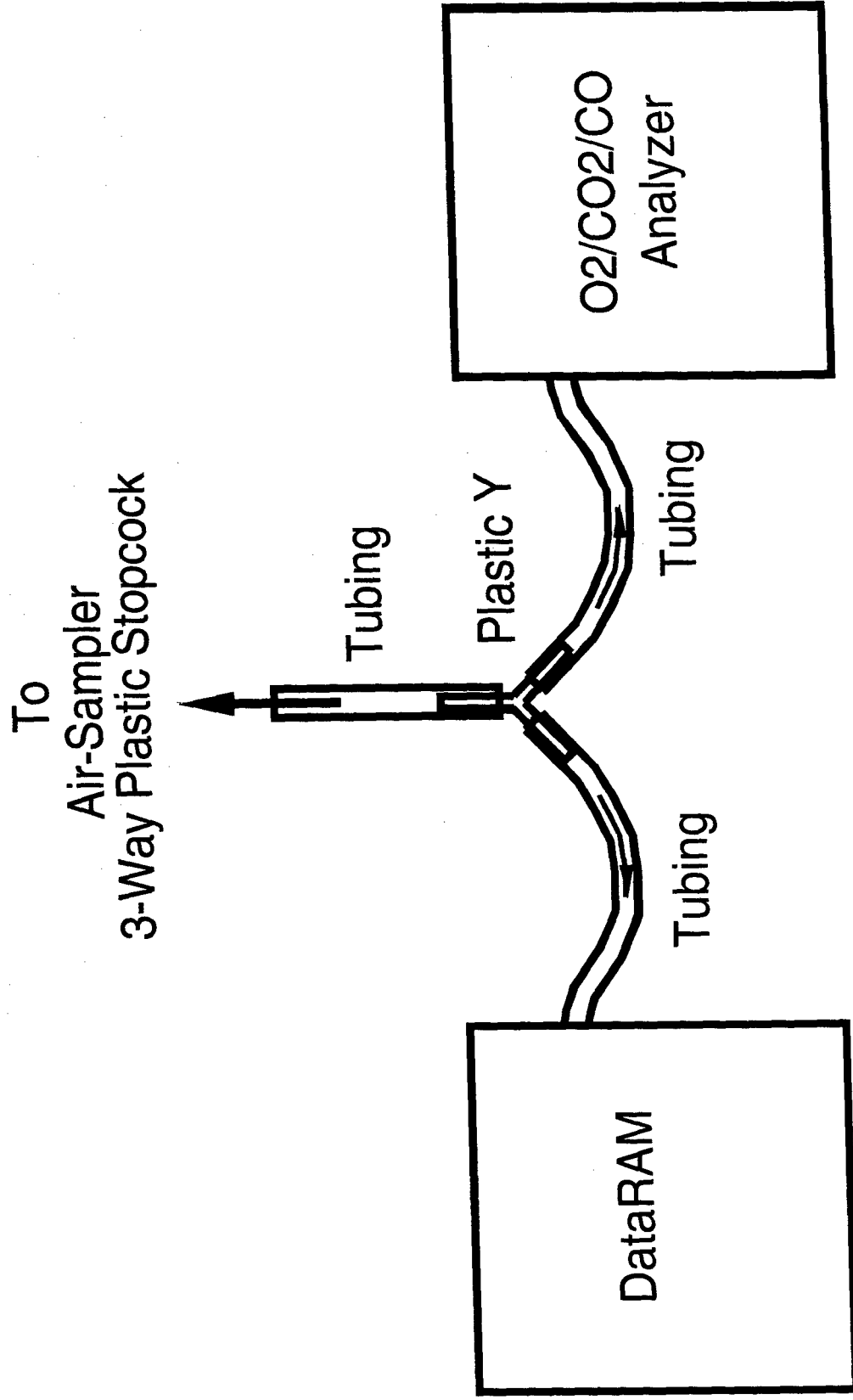




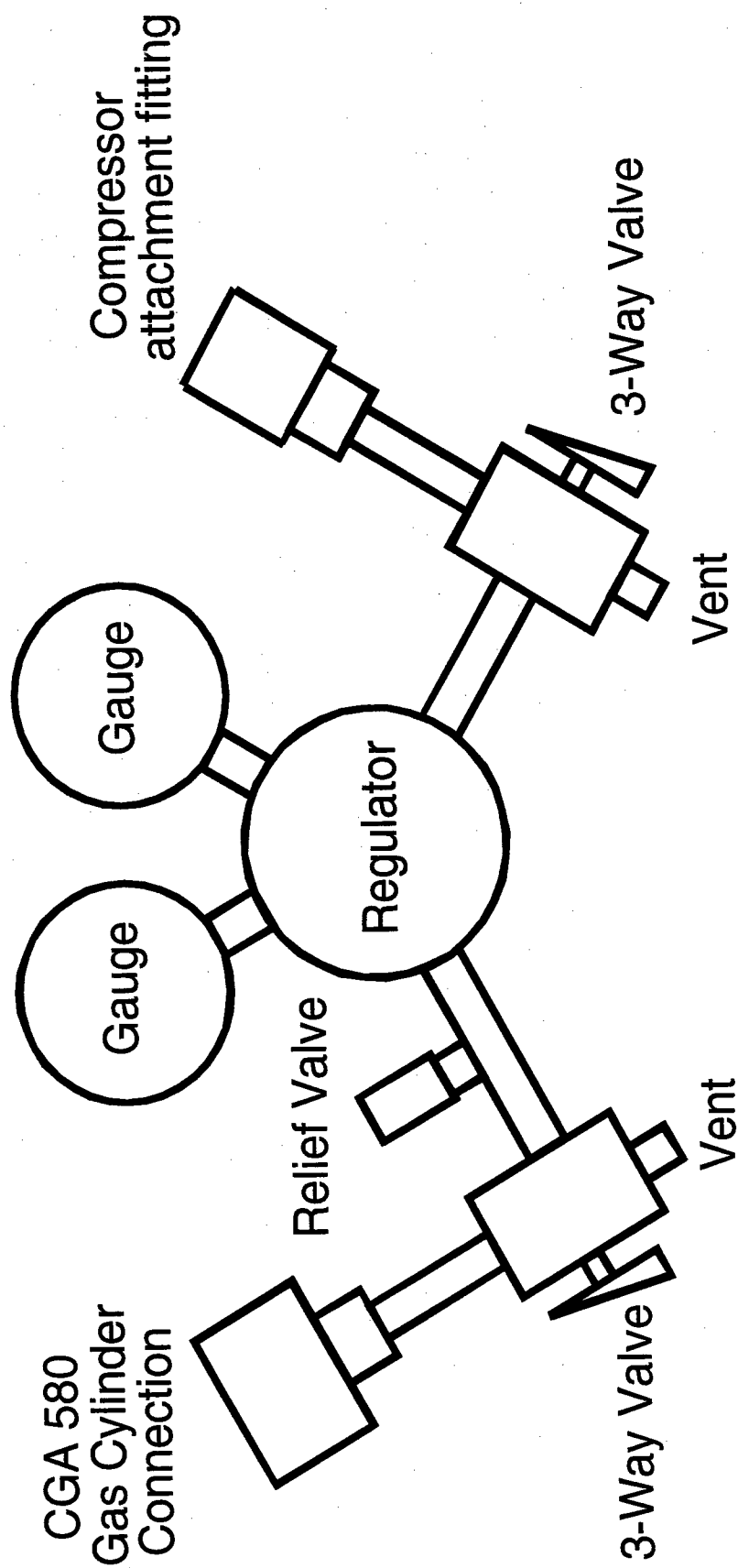
Figure B-2. Air-sampler.



**Figure B-3. Attachment to air-sampler.**



**Figure B-4. Gas cylinder sampling regulator.**



## AIR SAMPLING DATA SHEET

Date: \_\_\_\_\_ Facility: \_\_\_\_\_ Person(s) Sampling: \_\_\_\_\_

Compressor make & s/n: \_\_\_\_\_ Sample Site (valve or fitting #): \_\_\_\_\_

Compressor History (recent trouble or service, if any): \_\_\_\_\_

Weather conditions (if outside): \_\_\_\_\_

Notes (use back for additional): \_\_\_\_\_

Gas Cylinder Info:			Cal Gas Concentrations			
H <sub>2</sub> s/n	N <sub>2</sub> s/n	Cal Gas s/n	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Isobutylene ppm
Analyzer Info:						
Geotech S/N		DataRam S/N		TVA S/N		TVA Ignition Time
Calibration	Geotech			DataRAM	TVA	
Calibration	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Zeroed	Isobutylene ppm	
Time Calibrated						
Post - Cal Check						
Compressor Screening	Geotech			Data Ram MG/M <sup>3</sup>		
	O <sub>2</sub> %	CO <sub>2</sub> ppm	CO ppm	Max "Conc"	"Conc" * 0.5 oil mist corr.	Time
	TVA (neg=0)		Adjusted Reading		Methane corr	Odor?
	1) ppm w/o Char.	2) ppm w/ Char.	(1) - (2)	(neg=0)	Adj * 1.5 (neg=0)	Time
Readings						
High-Pressure Air Samples (if collected)						
	Cylinder #	Time Collected	Comments			
Sample 1						
Dup. Sample 2						